Environmental Pollution by Fluorides

in FLATHEAD NATIONAL FOREST and GLACIER NATIONAL PARK

By
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and
Jerald E. Dewey, Entomologist

U. S. DEPARTMENT OF AGRICULTURE
FOREST SERVICE

Division of State and Private Forestry
Forest Insect and Disease Branch
Missoula, Montana

Cover Photographs

Top — Plume created by the Anaconda Aluminum Company Plant at Columbia Falls, Montana. Teakettle Mountain is in background.

Bottom — Fluoride injury on lodgepole pine caused by emissions from the Anaconda Aluminum Company Plant.

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Summary

The U. S. Forest Service initiated a study in 1969 to determine: (1) the major cause of vegetational injury and damage on forested lands proximal to the Anaconda Aluminum Company, (2) the source of the cause, (3) the area affected, (4) whether insects were accumulating fluorides, and (5) if insect populations were being affected by fluorides.

Fluorides emitted from the Anaconda Aluminum Company were determined to be the primary cause of the injury and damage to vegetation in the surrounding area. Isopols, lines of equal pollution, were established for the area. Highest fluoride concentrations, up to 1000 ppm[1], in foliar tissue were found near the Anaconda aluminum plant. Data indicated the fluorides were carried by air movement from the aluminum plant through a saddle in Teakettle Mountain to Glacier National Park, following the pattern of the prevailing winds in the area. Elevated fluorides (greater than 10 ppm) were found in vegetation on Columbia Mountain and Teakettle Mountain, in vegetation near the towns of Columbia Falls, Hungry Horse, and Coram, Montana, and in the southwest portion of Glacier National Park. Varying degrees of visible fluoride injury were found on vegetation over more than 69,120 acres. Elevated fluorides were found in vegetation on nearly 214,000 acres of forested lands of mixed ownerships.

Although fluoride emissions were reduced during the summer of 1970, fir and spruce trees continued to accumulate fluorides at the same rate as in 1969.

Definite histological reactions to elevated fluorides occur in conifer needle tissue, including hypertrophy of parenchymatous cells.

Fluorides also were found to accumulate in insect tissue. All groups of insects studied contained high fluoride levels. Pollinators possessed the highest, up to 406 ppm. Cambium feeders contained in excess of 52 ppm, indicating that fluoride must be translocated in the cambium of trees. Predatory insects had fluoride counts over 53 ppm, showing fluoride is passed along the food chain. Insect population samples indicated that elevated fluoride levels in pine needles leads to a buildup of the pine needle scale.

[1] *ppm — parts per million*

Introduction

On August 15, 1955, the Anaconda Company formally dedicated a new aluminum reduction plant on their lands at Columbia Falls, Montana adjacent to the Glacier View Ranger District, Flathead National Forest. Partial operation of the plant had already begun using the Vertical Soderberg anode pot system. Anaconda Company officials insisted that injury caused to vegetation and animals by emitted fluorides would be negligible. F. J. Nietzling, Supervisor of the Flathead National Forest, wrote a letter to Glacier View District Ranger Mel Yuhas on June 27, 1957, and indicated ponderosa pine[1] trees in the vicinity of the reduction plant were dying. Subsequently, in July of 1957, Ranger Mel Yuhas, Bert Morris, Forester on the Glacier View District, and Don Leaphart[2], pathologist, Forest Service Inland Empire Research Center, inspected suspected fume damage near the aluminum plant. In a Forest Service memorandum Leaphart expressed his opinion that the injury was caused by fluoride fumes escaping from the reduction works. Little in the way of evaluation was done subsequently until 1969. In the meantime, the Anaconda Company expanded the plant in 1964-1965 and again in 1967-1968. Following the 1968 expansion and increased production, dead and dying trees and foliage necrosis were observed over the entire west face of Teakettle Mountain immediately east of the reduction works.

In preliminary evaluations in June and November 1969, we found tissue necrosis and elevated fluoride levels in 26 of 35 vegetation samples consisting of ponderosa pine, lodgepole pine, western white pine, and Douglas-fir. It became obvious that a detailed evaluation was needed to accurately assess the problem. In January of 1970 a study plan, designed to analyze the fluoride problem, was finalized.

Our hypothesis was that fluorides from the aluminum plant were causing ecological damage to flora and fauna. To test this hypothesis, the following objectives were outlined:

1. Identify the major cause of vegetational injury and damage on forested lands near the aluminum plant.
2. Identify the source of the cause.
3. Determine the area affected.
4. Determine if insects accumulate fluorides.
5. Determine if insect populations were fluctuating relative to the injury.

This report is divided into two phases: Pathological, dealing with objectives 1-3, and entomological, dealing with objectives 4 and 5.

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[1] *Scientific names of all plant and animal species mentioned in this report are listed in Appendix I.*

[2] *Now at Intermountain Research Station, Moscow, Idaho.*

Literature Review

Origin of Fluorides

Electrolytic reduction of alumina ($A1_2O_3$) produces pure aluminum. The electrolysis is done within a reduction cell or "pot" and is accomplished in the presence of the electrolyte cryolite (3 $NaF \cdot A1F_3$). Sodium fluoride (NaF) and aluminum fluoride ($A1F_3$) are released in particulate form as waste during the high temperature electrolysis (965° to 975° C.), and hydrogen fluoride (HF) and small quantities of carbon tetrafluoride (CF_4) are released as gases (Hickey, 1968). Hydrocarbons in considerable amounts are released. NaF, $A1F_3$, and HF are accumulated by and cause injury to plants. Although no highly reliable figures are available, it has been estimated that about half of the emissions are gaseous and half particulate (Semrau, 1957).

Fluoride emissions can be contolled to various extents by a process known as scrubbing. This involves the injection of a high-pressure spray of water or lime solution into the effluent stacks or the application of a low pressure scrubbing system, resulting in absorption of the fluorides (Hickey, 1968).

Effects on Vegetation

General. During the past 20 years, effects of fluorides on vegetation have been studied quite extensively in laboratory-controlled experiments and in field experiments proximal to aluminum reduction plants. Shaw, et. al. (1951) reported foliar necrosis and retarded diameter growth in ponderosa pine near the Kaiser Aluminum Company aluminum reduction plant at Mead, Washington. The injury could not be attributed to insects, fungi, nor climate, but was highly correlated with excessive foliar fluoride concentrations ranging to 600 ppm dry weight basis. Lynch (1951) found nearly a sixfold decrease in diameter growth rate in ponderosa pine near the same reduction plant and attributed the effect to fluorides. Adams, et. al. (1956) tested the sensitivity of ponderosa pine as an indicator of fluoride pollution and found it readily express visual symptoms (foliar necrosis).

A study made near the Harvey Aluminum Company reduction plant at The Dalles, Oregon (Compton, et. al. 1961), showed foliar necrosis of ponderosa pine to be related to elevated fluoride levels and not to fungal, climatic, nor insect agents. They also found abnormally large concentrations of black pine leaf scale in the affected area.

Treshow, et. al. (1967), reported mortality and growth decline of Douglas-fir near a phosphate reduction plant in Idaho. They found up to 100 percent reduced diameter growth when the foliar fluoride concentrations exceeded 50 ppm. Interestingly, they found increased shoot and needle elongation under insidious levels of fluoride pollution, but concluded the increased length was due to abnormal cell elongation and not excessive division.

Accumulation and Symptoms on Plants

Fluorides enter needles and leaves mainly through stomata. Once in the foliar tissue, they are in a soluble state, free-flowing and tend to accumulate at conifer needle tips or broadleaf margins, causing tip or margin necrosis. Because particulate fluorides are readily adsorbed to dust particles, dust on the leaf surface may aid in accumulating fluorides (Jacobson, et. al. 1966).

Hindawi (1970), through the use of colored pictures, vividly portrayed symptoms of fluoride injury. Browning of leaf margins and needle tips associated with a distinct demarcation line between healthy and injured tissue was a constant indicator of fluoride pollution.

Reductions in photosynthesis have been shown to occur in fluoride fumigated plants. Thomas (1961) reported a decrease in photosynthesis of up to 45 percent on *Gladiolus* plants, resulting in decreased plant vigor and growth.

Entomological Aspects

The literature pertaining to the effects of fluorides on insect populations is limited. In a study of blighted ponderosa pines near an aluminum reduction facility, Johnson (1950) found a significant increase of the black pine leaf scale as tree damage caused by fluorides increased. Lezovic (1969) indicated that in a study conducted near an aluminum factory "all colonies of bees, a total of 70, died off." Other authors reporting on fluoride injury to bees include Caparrini (1957), Guilhon et. al. (1962), Marier (1968), and Maurizio and Staub (1956).

Outram (1970) concluded sulphuryl fluoride caused a reduction in oxygen uptake and changes of respiratory quotient in the eggs of the desert locust, and the yellow meal worm. He said, "it is suggested that sulphuryl fluoride is nonspecific in respect to sites of attack in the insect egg and inhibits several metabolic processes."

Pollution by chemicals other than fluorides has been reported to indirectly affect insect populations. Stark et. al. (1968) in a study dealing with oxidants of photochemical air pollution (particularly ozone) stated that "air pollution injury predisposed ponderosa pine to bark beetle infestations."

Environmental Effects

Maclean et. al. (1969) showed that livestock forage accumulated enough fluorides to be a potential hazard to livestock. Little fluoride is taken in by breathing; most is ingested through foods, forage, etc. Marier et. al. (1969) pointed out that excessive inorganic fluorides in animals tend to be either excreted through the kidneys or accumulated in the teeth and skeletal tissues. In acute cases, excessive fluorides have caused skeletal fracture and disintegration of teeth, associated with severe pain. Normally, in animals feeding on foliage not contaminated by fluorides, fluorides in bones do not exceed 1000 ppm. However, ingestion by animals of fluoride-contaminated forage can lead to fluoride accumulations of 5000 ppm or more, at which levels severe fluorosis can occur (Marier, 1969).

Gordon (1969) in a study near the Cominco American phosphate fertilizer plant in western Montana found large concentrations of fluorides in femur bones of Columbian ground squirrel and concluded the fluorides were ingested with the contaminated forage. Available forage in the area was found to have excessive fluorides. No fluorosis in the animals was indicated.

Methods

Pathological Phase

Description of the Area

The Anaconda Aluminum Company reduction plant is located about 2 miles east of Columbia Falls, Montana, (fig. 1) at 3,100 feet m.s.l. (mean sea level). Teakettle Mountain rises abruptly to 5,936 feet m.s.l. immediately east of the plant. Columbia Mountain is 2 miles south and Glacier National Park 6 miles northeast of the plant. Topography west and southwest of the reduction plant is quite flat for 10 to 15 miles, but mountainous with deep valleys to the northwest, north, northeast, and southeast. The higher peaks in the general area attain an elevation of 8,000 to 9,000 feet m.s.l. The prevailing wind is southwesterly.

Because of the variable topography, a number of different habitat types are represented. The more common are: *Pseudotsuga menziesii — Symphoricarpos albus* h.t., *Abies lasiocarpa — Xerophyllum tenax* h.t.; and *Pinus albicaulis — Abies lasiocarpa* h.t. (Daubenmire and Daubenmire, 1968). A large variety of fauna, from grizzly bear and elk to small rodents, proliferate in the area.

The Aluminum Plant

The reduction plant is owned by the Anaconda Company. The physical plant is composed of five pot lines, each line containing 120 individual reduction pots, for a total of 600 pots(fig. 2). The Vertical Stud Soderberg Pot system is used for reducing the alumina to pure aluminum, a process shown to be one of the most problematical in terms of controlling effluents.

During 1969 and early 1970 the Anaconda Company reported fluorides were emitted at a rate of nearly 7,600 pounds per day but were reduced to about 5,000 pounds by September of 1970. By early May, 1971, company officials reported emissions were reduced to 2,500 pounds per day. Although the fluoride component of the effluent plume is nearly invisible, the hydrocarbon portion readily indicates the general direction of atmospheric transport of the pollutants.

Field Study Design

Control Plots. Two areas, one 30 miles south of Columbia Falls near Big Fork, Montana, and the other 30 miles west of Columbia Falls, about 15 miles west of Kalispell, Montana, were selected for control sampling. The locations were upwind of the aluminum plant in terms of the general prevailing southwesterly winds. Three plots, each one-hundredth acre in size (6.6 feet wide by 66 feet long), were installed in each area. All conifers and shrubs on the plots were sampled. Also, representative herbaceous plants and at least one grass species were sampled. We collected control samples in June-July and again in September-October, 1970.

Radial System. Ten radii, numbered consecutively from 1 to 10, were established extending from the aluminum plant into adjacent forested lands (figure 1). The direction of each radius was based on two criteria: (1) it must transect National Forest land, and (2) it should follow suspected wind channels. On each radius, basic plots one-hundredth acre in size (6.6 feet wide by 66 feet long, oriented longitudinally) were established at one-fourth, one-half, 1, 2, 4, 6, and 8 miles from the plant. Be-

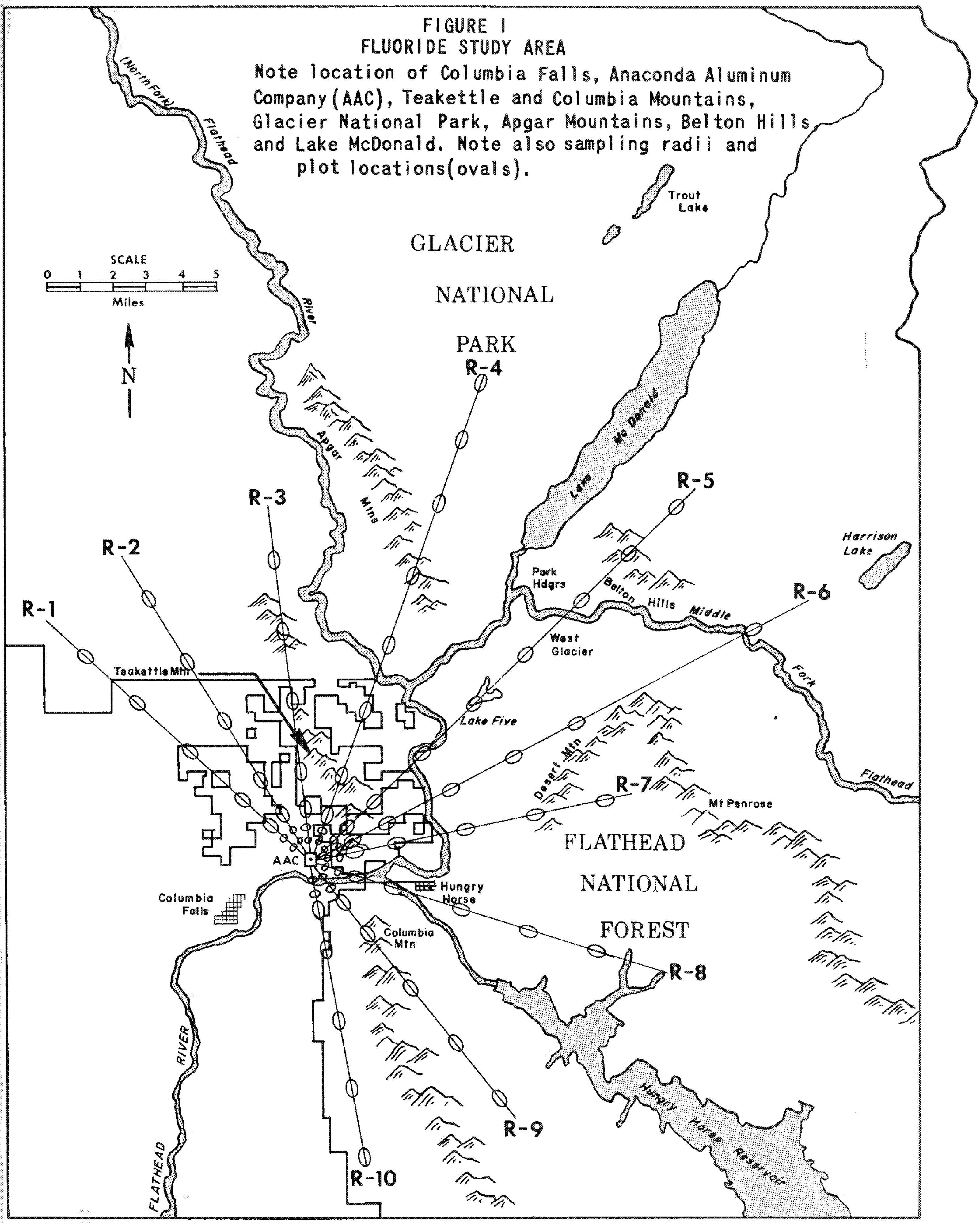


FIGURE I
FLUORIDE STUDY AREA
Note location of Columbia Falls, Anaconda Aluminum Company (AAC), Teakettle and Columbia Mountains, Glacier National Park, Apgar Mountains, Belton Hills, and Lake McDonald. Note also sampling radii and plot locations(ovals).
GLACIER NATIONAL PARK
FLATHEAD NATIONAL FOREST
SCALE
0 1 2 3 4 5
Miles
N
(North Fork) Flathead River
Trout Lake
Lake McDonald
Harrison Lake
Apgar Mtns
Park Hdqrs
Belton Hills
Middle Fork Flathead
West Glacier
Lake Five
Teakettle Mtn
Desert Mtn
Mt Penrose
AAC
Columbia Falls
Hungry Horse
Columbia Mtn
Hungry Horse Reservoir
FLATHEAD RIVER
R-1
R-2
R-3
R-4
R-5
R-6
R-7
R-8
R-9
R-10

cause radii 4, 5, and 6 intercepted Glacier National Park, additional plots were established at 10, 12, and 14 miles on radii 4 and 5 and at 14 miles on radius 6 to sample vegetation in the Park. Each plot was permanently established as witnessed by driving a wooden stake at the plot location with plot information written on it.

Collection of Vegetation on Control and Radial Plots. Plots were sampled twice, once during June-July 1970, and again in October-November 1970. For convenience, we termed the June-July collection the "first sampling" and the October-November collection the "second sampling." About 3 pounds of foliage on each plot were collected and maintained separately from one to several representatives of each conifer species, one representative of each of two shrub species, and one representative of each of one herbaceous and one grass species. Foliage collected from each grass, broadleaf plant, and deciduous conifer was considered a separate sample. Foliage collected from other conifers was separated by year of origin, and foliage of each year was considered a separate sample. Generally only 1969 and 1970 needles were sampled. For conifers, the sample was always collected from dominant and codominant trees and always in the upper one-third of the crown facing the aluminum plant. Samples from other types of vegetation were collected as foliage was available.

Special sampling. In addition to the systematic field design, a supplemental series of "special samples" were collected in areas deemed most likely to sustain high fluoride levels. Because fluorides are transported in atmosphere, vegetation on ridges and prominent topography downwind from the prevailing winds over the aluminum plant may be more likely to intercept fluorides than vegetation in valleys or other areas. The general locations of special sampling are shown in figure 3. The locations were: 1) near Columbia Falls, 2) Columbia Mountain, 3) Teakettle Mountain, 4) Southwest Glacier National Park, 5) Coram Experimental Forest, near Desert Mountain, and 6) northeast edge of Hungry Horse Reservoir. Samples were not collected on a plot basis as described for the radial collections; rather, vegetation representative of the area, with emphasis on coniferous species, was collected in June and again in October 1970. A sample was defined as stated in the section on Collection of Vegetation.

Laboratory Study Design

Visual Burn. All vegetation samples were brought to the laboratory for analysis of visual burn. For each conifer sample, needles were sorted according to year of origin, 1969 or 1970. The proportion of different needles showing evidence of foliar burn was recorded (Carlson and Dewey, 1970). Also the average proportion of length of burn on affected needles was estimated. For shrubs, the proportion of different leaves showing burn symptoms was estimated, and burned on leaves, the actual proportion of area affected was estimated. Symptoms on grasses could not be measured. Extreme care was exercised to avoid confusing insect or disease injury with fluoride burn.

Chemical Analysis. After estimation of foliar burn, separate subsamples of 30 to 40 grams of foliar tissue from samples of 1969 and 1970 needles of each conifer species and from one sample of each of two shrub species from each plot were prepared for chemical analysis of available fluorine (i.e., gaseous and particulate). A subsample of grass and herbaceous tissue from each plot was similarly prepared. All samples were sent to WARF Institute, Inc., Madison, Wisconsin, for analysis. The semi-sutomated method as outlined by Health Laboratory Science (1969) was used for determination of total fluorine. Results were given in ppm (parts per million) dry weight basis. For the purposes of this report, the terms "fluorine" and "fluoride" will be used interchangeably.

Histological Analyses

Solberg and Adams (1956) and Gordon (1970) in controlled studies described histological responses of conifers to fumigations by fluorides. Protoplasmic and nuclear hypertrophy of parenchyma cells resulting in death of foliar phloem tissue were regarded as symptomatic of fluorosis in conifer tissue. Therefore, we arbitrarily selected subsamples from burned conifer needles for histological analysis of tissue showing fluoride burn. Approximately 2 mm. sections of tissue were extracted from the "transition zone" (that portion between the green and burned tissue on

Figure 2. — Anaconda Aluminum Reduction plant at Columbia Falls, Montana. Note effluent from the five pot lines. View is southerly, Columbia Mountain is in background.

the needles). The sections included green, chlorotic, and necrotic tissue. The specimens were killed and fixed in formalin-aceto-alcohol, dehydrated through a tertiary butyl alcohol series, embedded in paraplast, sectioned at 9 micra thickness on a rotary microtome, and examined and photographed through a Leitz Ortholux phase contrast microscope equipped with an Aristophot photographic system.

Aerial Photography

The entire area suspected to be affected by fluorides was photographed in July of 1970 with Aero Ektachrome, 9x9 format, at a scale of 1:12000. In addition, stereo pairs were taken of all the radial plots at a scale of 1:4000.

Entomological Phase

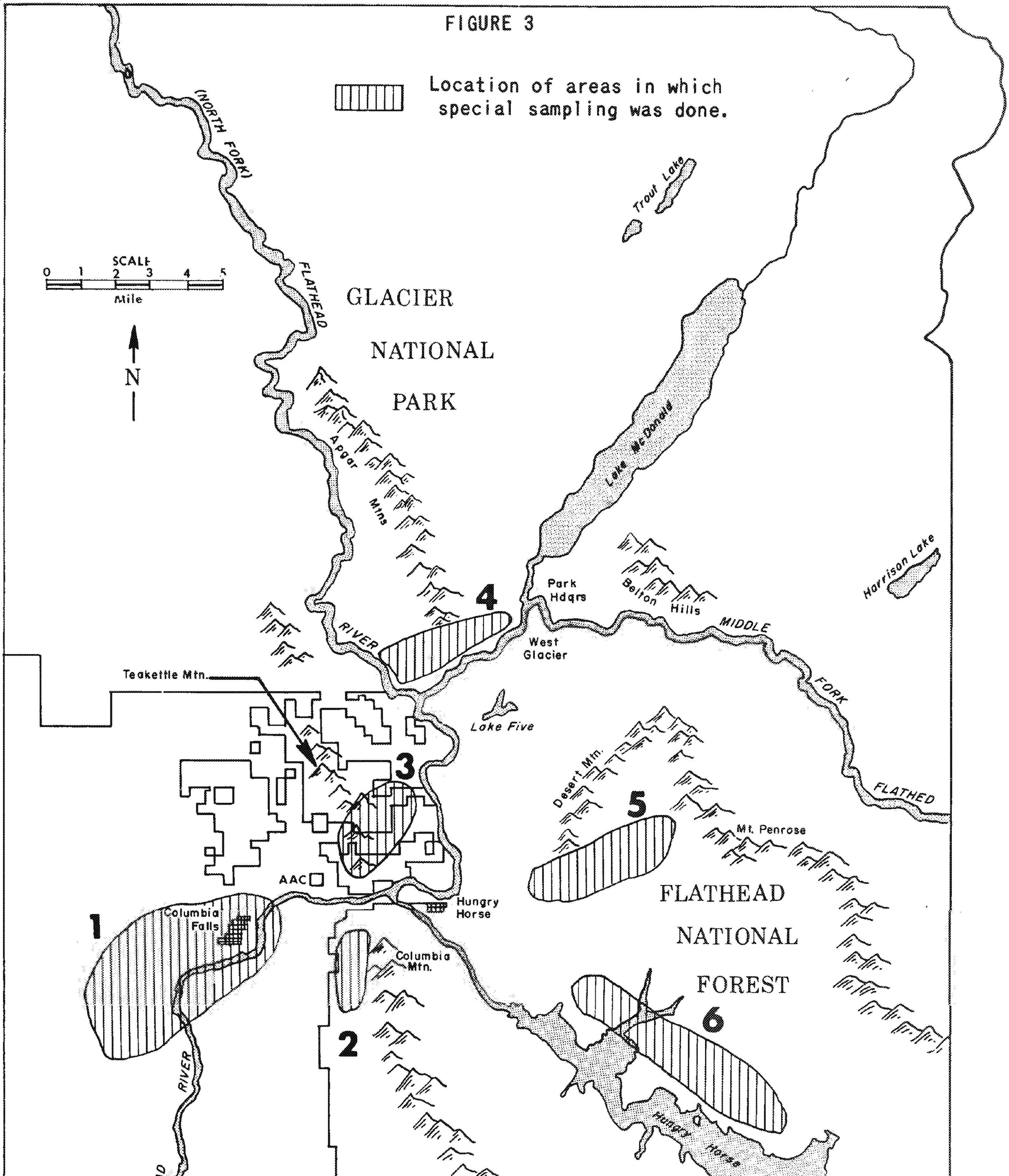
Accumulation of Fluoride by Insects

A broad spectrum of insects including foliage feeders, cambium feeders, pollinators, and predators were sampled and analyzed for fluoride accumulation (Appendix VI). At least 5 grams of each species were oven dried and sent to WARF for analysis of available fluoride (5 grams = from 100-500 individual insects, depending on the species.) Insects were collected in the spring (June 1), summer (August 12), and fall (October 9), 1970, on the basis of their availability. All collections were made within one-half mile of the aluminum plant except for eight control samples that were taken at least 50 miles from the plant. The less common insects were sent to the U. S. National Museum for identification; the remainder were identified by Jerald E. Dewey.

Insect Population Sampling

Controls. Two forest insects, larch casebearer and pine needle scale, were sampled in an attempt to relate population numbers to fluoride accumulations. Control samples were taken 30 miles to the north, south, east, and west of the plant. Larch casebearer populations were measured using the system described by Bousfield (1969) in which casebearers per 100 larch spurs were measured. Pine needle scale populations were measured modifying the method reported by Fischer (1950) in which scales per linear inch of "new" and "old" foliage were counted. Values of scales per 600 needles were obtained.

Radial Sampling. To determine if insect populations were increasing, decreasing, or remaining static in relation to distance from the suspected fluoride source and to foliar fluoride content, sampling was conducted in mid-April 1970, for populations of larch casebearer and pine needle scale, along the established radii. The same procedures were used as described above. Sample intervals were one-fourth, one-half, 1, 2, 4, and 8 miles from the aluminum plant.



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Results

Pathological Phase

Parameters

The following parameters were used in the evaluation of the pollution problem:

1. **Fluoride content** — Available fluoride content of whole leaves and whole needles of plants, dry weight basis, in ppm.

2. **Injury index** — The concept of injury index (I.I.) was developed after the field data were collected. Let P equal proportion of different needles showing fluoride burn symptoms for a given sample and let R equal the Ratio of length of burn on burned needles of the same sample, as described previously. Then the product PR would be an estimate of the gross amount burned for foliage of a given year. A similar value can be computed for broadleaf plants. We have termed this value the "injury index" for a given sample. Estimations of foliar burn for determining injury index were done on all samples (except grasses) collected the first sampling period, but only on conifers the second. An early freeze caused premature death of broadleaf foliage, making estimation of burn nearly impossible.

Control Plots

Fluorine Content. One hundred and nine control samples, including collections of both sampling periods, were analyzed chemically. Data for fluoride accumulation in vegetation were classified and grouped as shrub, 1969 conifer, 1970 conifer, herbaceous, and grass (Appendixes II-A and II-B) and were subjected to a four-factor analysis of variance shown in table I-A. The means for factors are shown in table I-B.

Only means in vegetation type showed significance: the other factors were insignificant. The significance in vegetation type was vested between 1970 conifer tissue at 6.17 ppm and the grass tissue at 10.73. All factors, with the exception of grass species, had average fluoride content of less than 10 ppm. Therefore, we selected 10 ppm fluoride as a conservative control or "background" level for all plant tissue sampled in the study.

Injury Index. For all control samples in the first sampling the average injury index (I.I.) was 0.001; for the second sampling was 0.000. Thus we arbitrarily established a higher value of 0.006 as a conservative control level for injury index; i.e., only samples having an I.I. greater than 0.006 would be considered visually injured by fluorides. To further substantiate I.I. as a parameter for evaluating foliar fluorosis we made a nonparametric analysis over all the samples, control and otherwise, including both sampling periods and found that of 237 samples having an I.I. exceeding 0.006, 227 had fluorine concentrations greater than 10 ppm and 10 had less than 10 ppm. Thus, 96 percent of the time an I.I. exceeding 0.006 was highly indicative of elevated (abnormal) fluoride levels. However, many samples having high fluoride levels did not show injury. Therefore, I.I., at best, is a useful but very conservative parameter for estimating fluoride pollution.

Radial System

Fluoride Content. For the purpose of demonstrating general pollution levels, fluoride

Table I-A. — Analysis of variance of control data, fluoride content

Source of variation	Degrees of freedom	Sum squares	Mean squares	F ratio	Significance
Collection period	1	27.2431	27.2431	2.75	NS[1]
Area	1	27.4862	27.4862	2.78	NS
Plots	2	23.0648	11.5324	1.17	NS
Vegetation type	4	158.2020	39.5504	4.00	*[2]
Residual	51	504.3950	9.8900		
Total	59	704.3950			

[1] *NS = Non-significant*
[2] * *= Significant at the 95 percent level*

Table I-B. — Means for factors, control data

Factor	Level	Mean
Collection period	June	7.671[3]
	October	9.018
Area	I	7.668
	II	9.021
Plot	1	9.136
	2	7.622
	3	8.276
Vegetation type	Shrub	8.324
	Conifer, 1969	7.076
	Conifer, 1970	6.171
	Herbaceous	9.423
	Grass	10.729
Grand mean		8.344

[3] *Fluoride content, ppm*

content values were averaged separately on a plot-by-plot basis, irrespective of the general vegetation type. This procedure was considered quite valid because very nearly the same amount and type of vegetation was collected from all plots sampled and would be readily comparable to the plot-by-plot analysis of control data mentioned previously. (Control plot averages did not show significance and were less than 10 ppm). However, on all 11 of the plots located very close to the reduction plant, conifers had been killed, apparently from fluorides, and samples could not be obtained. Results are tabulated in Appendix II-A (first sampling) and Appendix II-B (second sampling). Blanks in data indicate the vegetation type was not found on the plot. A total of 1,254 samples obtained during both sampling periods were chemically analyzed.

For every radius there exists a general trend of very high fluoride content near the aluminum plant, decreasing to control levels at the furthest plots. One can easily see from the tables the same general trend exists for separate vegetational types as exists for the plot averages, thus supporting our decision to use plot averages. In figure 4, the fluoride gradients from the grand average column, Appendix II-B, are schematically portrayed. On all the radii the lines of increasing concentration converge at the aluminum reduction plant, indicating the source of the fluorides. In figures 5, 6, and 7, we have graphed for radii 4, 5, and 6 respectively, the fluoride concentration data from the grand average column, Appendix II-B (second sampling period) against distance from the aluminum plant. We termed these graphs "Radial Profiles." These specific radii were selected for discussion because: 1) they are representative of all radii, and 2) they extend into Glacier National Park. The right ordinate depicts fluoride concentration from 10 to 10,000 ppm, (10 ppm is the control level) and the abscissa represents distance from the plant in miles. The data was plotted on logarithmic paper to accentuate smaller fluoride values. Plots located in Glacier National Park are designated by G.N.P.

The general shape of the fluoride curve is similar on all three radii, and similar on the other seven radii sampled, and shows abnormally high fluoride concentrations occurred (above 10 ppm) up to 12 and 14 miles from the reduction plant, including lands within Glacier National Park.

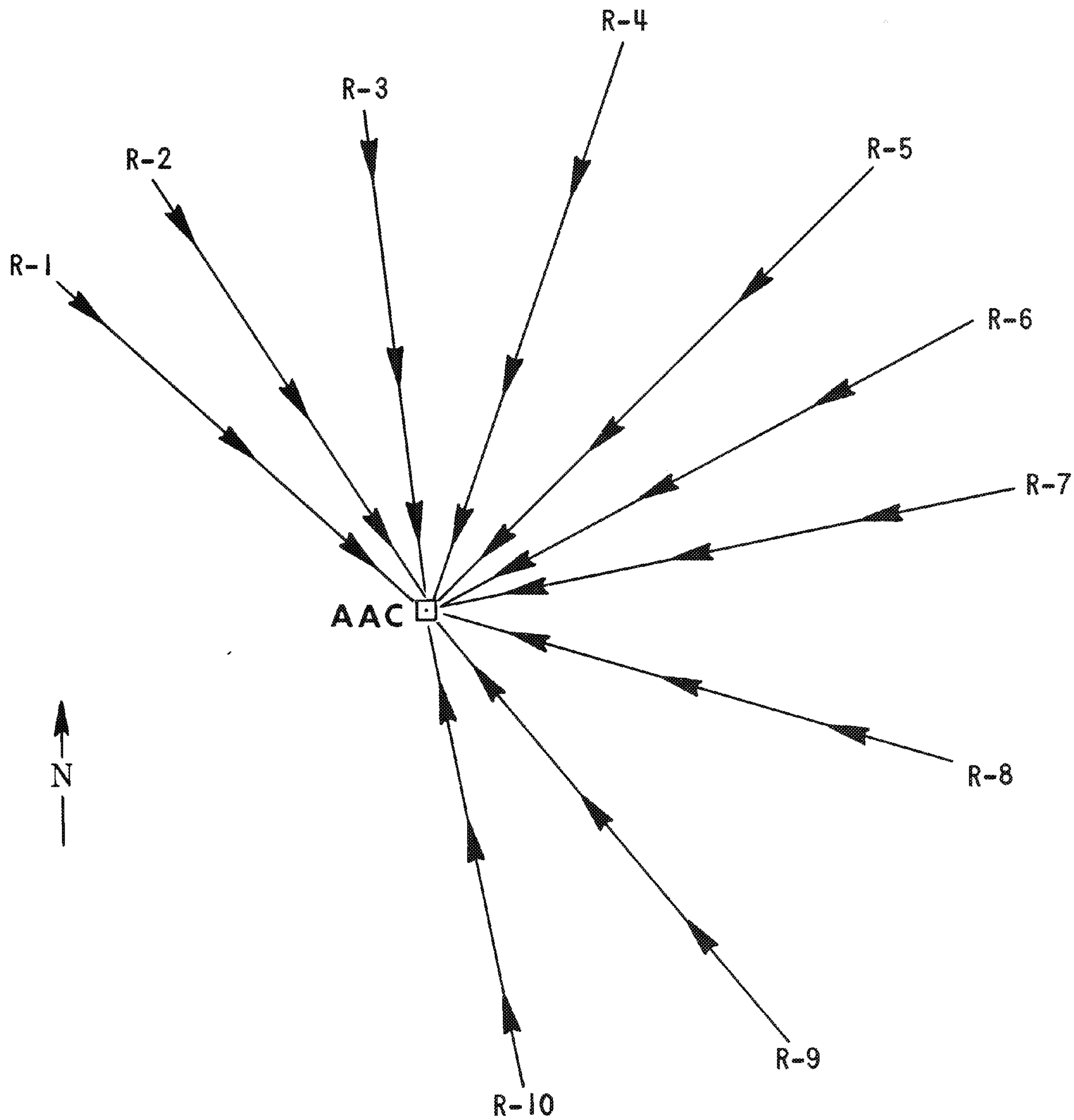
To simplify interpretation of the fluoride data, a single diagram was prepared that depicts virtually the entire extent of the pollution (figure 8). From the graphs of all the radial profiles, second sampling, we interpreted the distance at which average plot fluoride concentrations equalled the arbitrarily established levels of 10, 15, 20, 30, 60, 100, 300, and 600 ppm. Those distances were plotted on the radii, and then equal pollution (fluoride concentration) levels were connected by lines. These lines of equal pollution are termed "isopols." Data from the first sampling gave a similar figure, as did data for the separate vegetational categories. One can easily see the area of fluoride "fallout" and the various levels of average concentration. The distribution of fluorides generally corresponds with the prevailing southwesterly winds.[1] The areas included within (total area within a given isopol, including all area sustaining fluoride levels equal to or greater than the given isopol) and between (the area between two given isopols, such as the area between the 30 and 60 isopols) isopols are tabulated in Appendix III-A. Vegetation on approximately 214,000 acres had accumulated more than 10 ppm fluoride, on 69,120 acres had accumulated 30 ppm or more, and on 7,040 had accumulated 100 ppm or more. (The isopols southwest of Columbia Falls were constructed from special sample data and may not be as reliable as those estimated from radial data. They are, however, indicative of the general pattern in a southwesterly direction.) Much vegetation in the area within the 30 ppm isopol has been affected to various degrees by fluorides from the aluminum plant.

Injury Index. Injury index values were averaged separately on a plot by plot basis for fluoride content, irrespective of vegetation type (Appendix II-A and II-B). However, plot

[1] *The Environmental Protection Agency collected detailed information on meteorological conditions in the area and will publish the findings soon.*

FIGURE 4

Schematic diagram showing increasing concentration of fluorides in vegetation in the direction of and converging at the Anaconda Aluminum. The arrows represent the direction of increasing concentration.



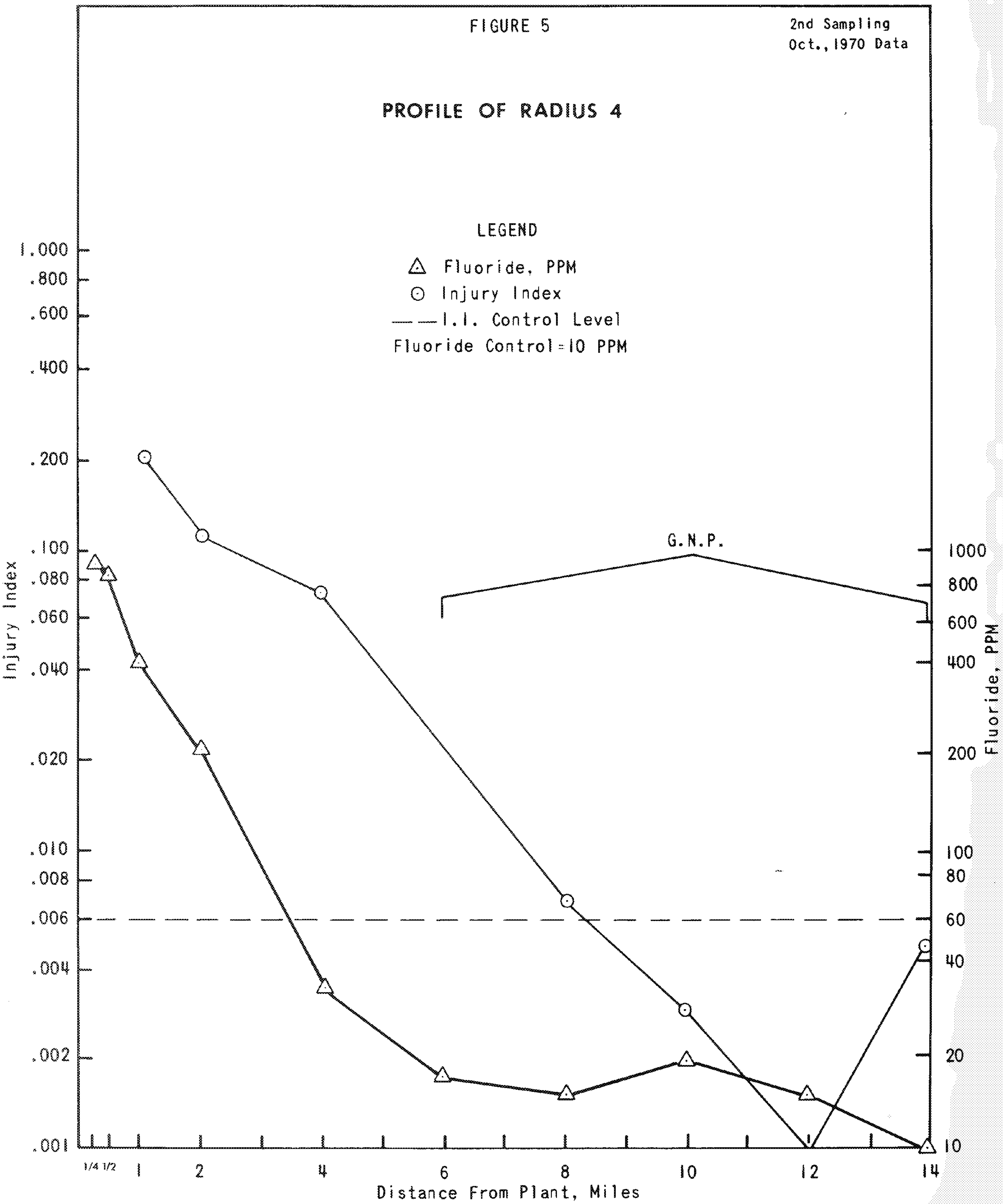


FIGURE 5
2nd Sampling
Oct., 1970 Data
PROFILE OF RADIUS 4
LEGEND
Fluoride, PPM
Injury Index
I.I. Control Level
Fluoride Control = 10 PPM
G.N.P.
Injury Index
Fluoride, PPM
1.000
.800
.600
.400
.200
.100
.080
.060
.040
.020
.010
.008
.006
.004
.002
.001
1000
800
600
400
200
100
80
60
40
20
10
1/4 1/2 1 2 4 6 8 10 12 14
Distance From Plant, Miles

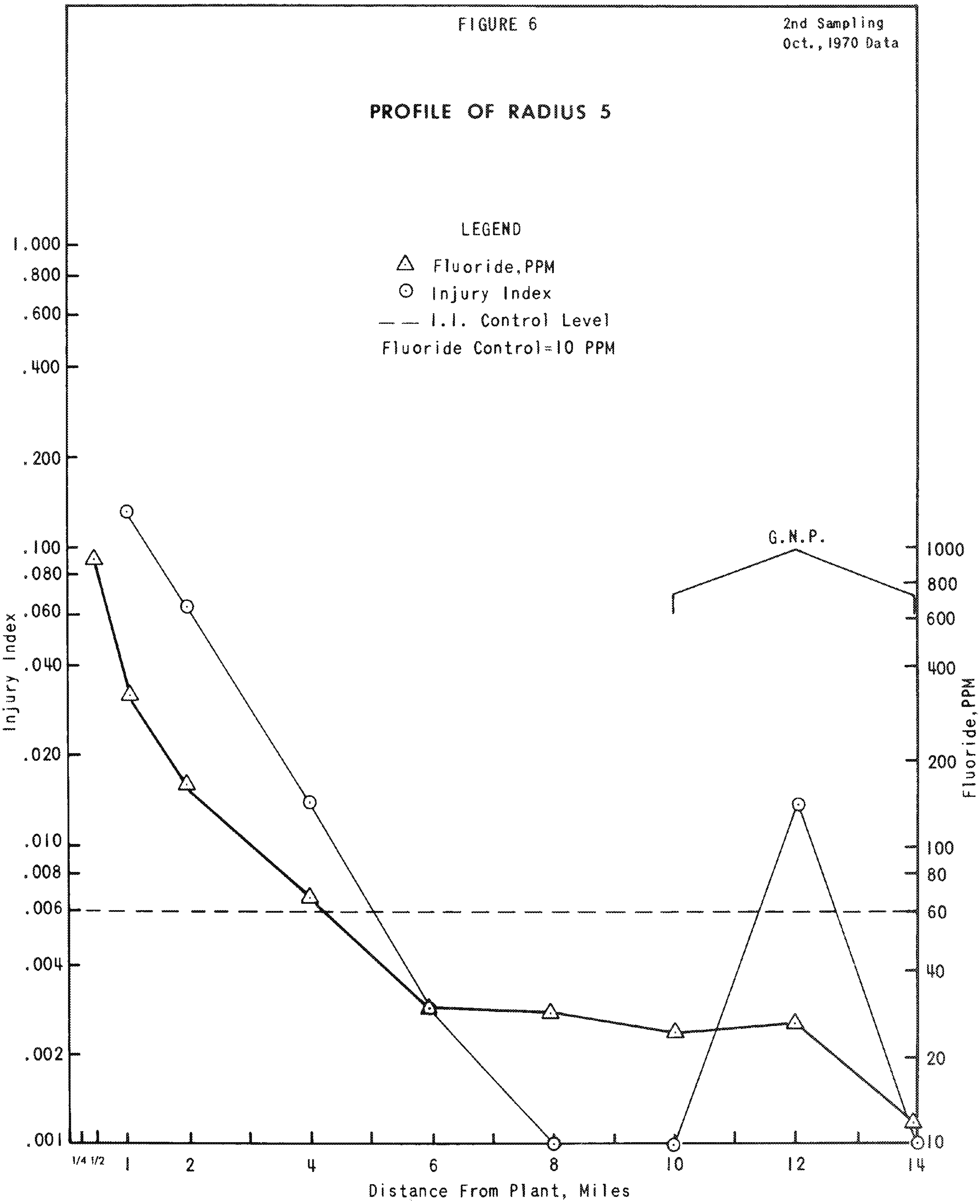


FIGURE 6
2nd Sampling
Oct., 1970 Data
PROFILE OF RADIUS 5
LEGEND
Fluoride, PPM
Injury Index
I.I. Control Level
Fluoride Control=10 PPM
G.N.P.
Injury Index
Fluoride, PPM
1.000
.800
.600
.400
.200
.100
.080
.060
.040
.020
.010
.008
.006
.004
.002
.001
1000
800
600
400
200
100
80
60
40
20
10
1/4 1/2
1
2
4
6
8
10
12
14
Distance From Plant, Miles

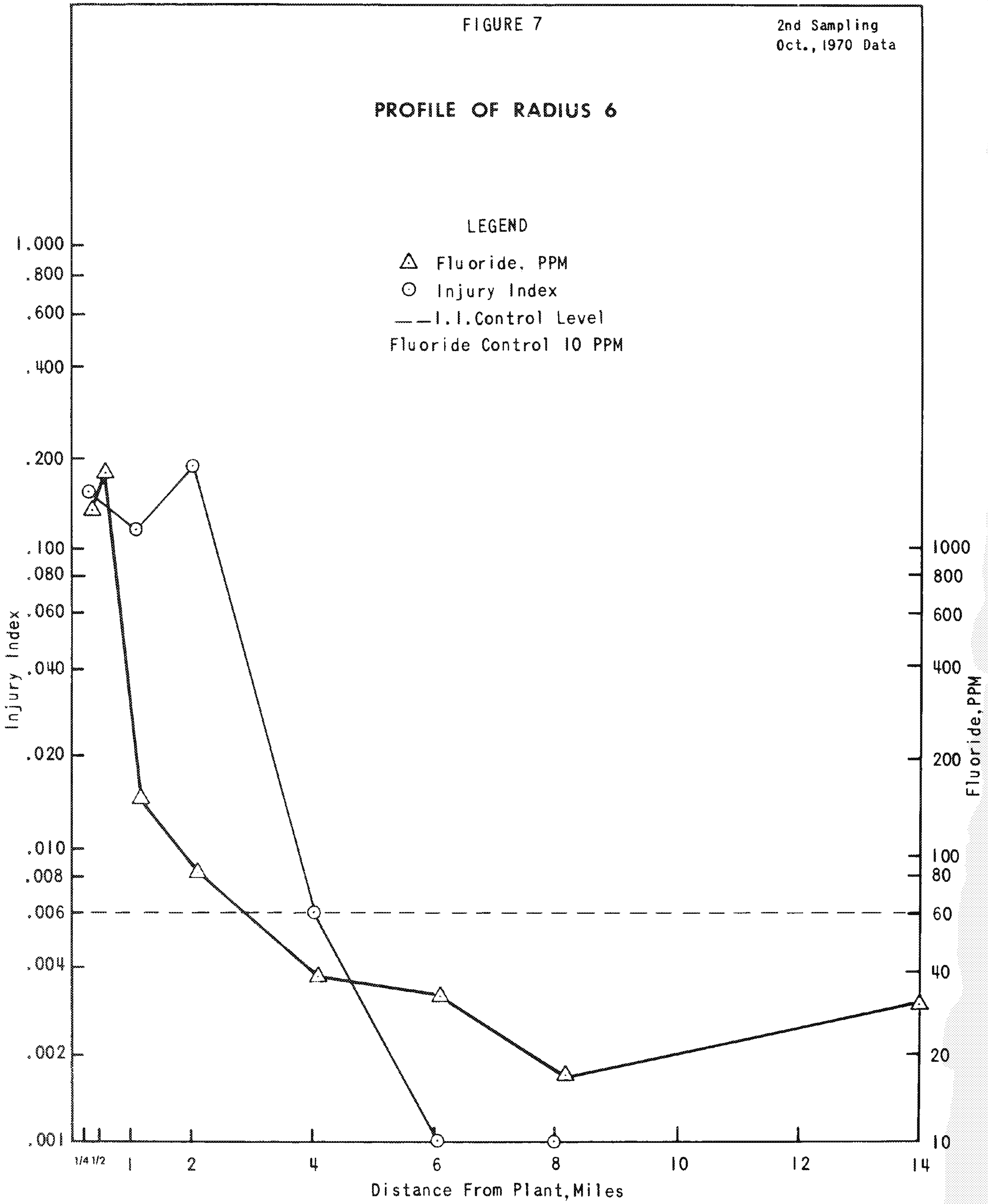
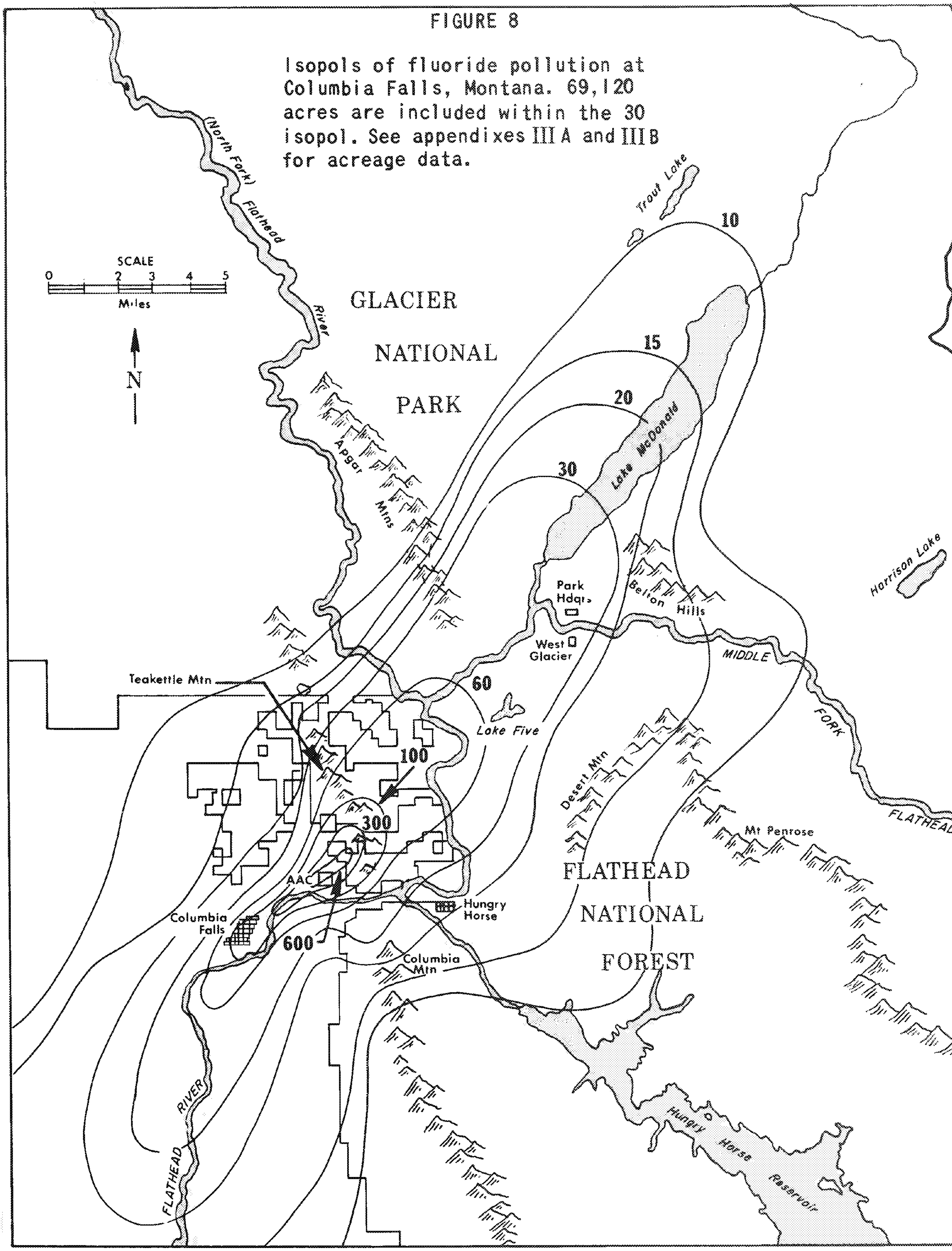


FIGURE 7
2nd Sampling
Oct., 1970 Data
PROFILE OF RADIUS 6
LEGEND
Fluoride, PPM
Injury Index
I.I.Control Level
Fluoride Control 10 PPM
Injury Index
1.000
.800
.600
.400
.200
.100
.080
.060
.040
.020
.010
.008
.006
.004
.002
.001
Fluoride, PPM
1000
800
600
400
200
100
80
60
40
20
10
1/4 1/2
1
2
4
6
8
10
12
14
Distance From Plant, Miles

FIGURE 8

Isopols of fluoride pollution at Columbia Falls, Montana. 69,120 acres are included within the 30 isopol. See appendixes III A and III B for acreage data.



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averages were determined by considering only those samples that had an I.I. of 0.001 or greater. Radial profiles of I.I. values were made for all radii separately for each sampling period. Only radii 4, 5, and 6 - figures 5, 6, and 7, respectively were selected for inclusion in this report, for the same reasons as outlined in the previous section on fluoride content. The left ordinate depicts I.I. values from 0.001 to 1.00. The abscissa represents distance in miles from the aluminum factory. The graphs indicate a decreasing amount of visual injury at increasing distances from the aluminum plant. Visual injury was found up to 8.5 miles from the factory on radius 4, up to 12 miles on radius 5, and up to 4 miles on radius 6. Generally, visual injury was found on sensitive species (Western white pine, lodgepole pine, and ponderosa pine) within the 30 isopol.

High injury indices were nearly always associated with values of fluoride concentration above 100 ppm. From data collected the second sampling period, we found the average injury index for plots 1-4, radii 3-8, was 0.142. As mentioned previously, of vegetation collected during the second sampling period, only conifers were analyzed for I.I. Radii 3-8 all transected a part of Teakettle Mountain, and plots 1-3 occurred on the west face of Teakettle Mountain. Plots No. 4 were on the east side of Teakettle, just over the crest of the ridge. All these plots had average fluoride values more than 100 ppm, as indicated in Appendixes II-A and II-B. Because the greatest and most obvious amount of visual injury occurred on the west face of the mountain, we used this area as a basis for establishing the classes of injury as shown in Table II.

Table II. — Classification of Visual Injury of Conifers

Class	Average injury index
Non-injured	< 0.006
Light	0.007 - 0.050
Moderate	0.051 - 0.099
Severe	> 0.100

In general, conifers on most of the west face of Teakettle Mountain have been severely injured by fluorides; on the north face of Columbia Mountain have sustained moderate injury; and on the east face of Teakettle have showed moderate injury. Vegetation, especially ponderosa pine, within the city of Columbia Falls has been injured moderately to severely by fluorides.

Visual injury to vegetation between the 30 and 100 isopols was restricted primarily to the conifers — lodgepole pine, western white pine, whitebark pine, ponderosa pine, and Douglas-fir. However, the forb lily of the valley proved to be very sensitive to fluorides and showed typical symptoms within the 30 isopol.

The most serious visible injury to vegetation occurred in the 19,840 acres included within the 60 ppm isopol. In 12,800 acres between the 60 and 100 isopols, 100 percent of the foliage of lodgepole pine showed partial necrosis, of which 50 percent was necrotic due to fluorides. The remaining 50 percent had been infested by four different insect species: sugar pine tortrix, pine needle scale, needle sheath miner, and a needle miner (figure 9). A causal relationship was not established between elevated fluorides and insect infestation; however, it would seem more than coincidental that the infestation was associated so closely with the high fluorides.

In the 5,760 acres between the 100 and 300 isopols, insects subsided to endemic levels. However, foliage of nearly all vegetation, including shrubs, forbs, and conifers, showed moderate fluoride burn. In 1,280 acres within the 300 and 600 isopols, foliage of all vegetation except grasses was severely burned (figures 10 and 11) and conifers exhibited terminal dieback (figure 12).

Special Samples

Fluoride Content and I.I. Data concerning fluoride content and injury index collected on a total of 175 special samples were very similar to radial data collected in the same areas. Data is shown in Appendix IV. High levels of fluorides, up to 290 ppm, were found in the Columbia Falls area. Moderate levels up to 86.5 ppm along with moderate foliar injury were found on Columbia Mountain, and up to 1163 ppm were found in 1969 Douglas-fir needles on Teakettle Mountain. Injury was

Figure 9. — Fluoride and insect injury on lodgepole pine from the east side of Teakettle Mountain. About 50% of the needles show typical fluoride burn (1); the rest are infested separately by sugar pine tortrix (2); pine needle scale (3); a needle sheath miner (4); and a needle miner (5).

severe on Teakettle Mountain. Fluoride levels between 20-30 ppm in 1969 conifer tissue were common in southwest Glacier Park. Light to moderate foliar injury also was found. Light fluoride accumulations between 15-20 ppm and little injury was found on the Coram Experimental Forest, and little fluoride or injury was found along the northeast edge of Hungry Horse Reservoir.

Much of the special data was used in the verification of isopols and the extension of isopols southwest from the aluminum plant.

Relation Between Injury Index and Fluoride Content

As explained previously, each sample collected was subjected to both a fluoride analysis and estimation of I.I. Because excessive fluorides can cause injury to plant tissue, one can hypothesize a positive correlation between fluoride level and I.I. We tested this hypothesis by regression analysis separately on 1969 and 1970 conifer needles and shrub foliage. Data obtained from radial plots and special samples were used, combining data for both sampling periods. Results of the analysis are shown in Appendix V. The correlation was positive and significant at the 99 percent level of confidence for 1969 conifer needle tissue. The "F" ratio for slope was also highly significant. For 1970 conifer needles and for shrubs, the correlation was nonsignificant. This analysis readily substantiated that for 1970 conifer tissue and for all broadleaf tissue tested, high fluoride levels existed without corresponding visible necrosis or burn.

Rates of Accumulation

To obtain a comparison of the relative rates of fluoride accumulation for 1969 and 1970 coniferous tissue, accumulations in 1969 tissue were paired with accumulations in 1970 tissue sampled from the same tree. Data collected from the radial plots and special samples, second sampling period, were used. The data was stratified by isopol and species type as shown in Table III. Values given in the table are average monthly fluoride accumulations in excess of the normal 10 ppm background level. The rate for 1969 tissue was found by dividing the total excess fluoride by 17 (total length of exposure in months) and by 5 for 1970 tissue.

The data indicates for pines that the rate of accumulation was about the same in 1970 as in 1969 between the 60-600 isopols but slowed down between the 10-60 isopols. The firs and spruces maintained about the same rate in 1970 as in 1969 for all the isopols.

Histological Results

Definite histological reactions were found in internal tissue of necrotic conifer needles. As described previously a 2mm piece of needle was taken from the "transition zone" between healthy and necrotic tissue and sec-

TABLE III

Rates of Fluoride Accumulation
Species Type [1]

	Pines		Firs and spruces	
Isopol	1969	1970	1969	1970
300 - 600	12.69	16.26	30.16	32.26
100 - 300	16.73	8.27	24.11	15.76
60 - 100	4.56	7.22		
30 - 60	1.69	0.54	1.54	1.22
10 - 30	0.67	0.45	0.94	1.58

[1] *"Pines" includes ponderosa, western white, whitebark, and lodgepole pines. "Firs and Spruces" includes Douglas, grand, and subalpine firs and Engelmann spruce.*

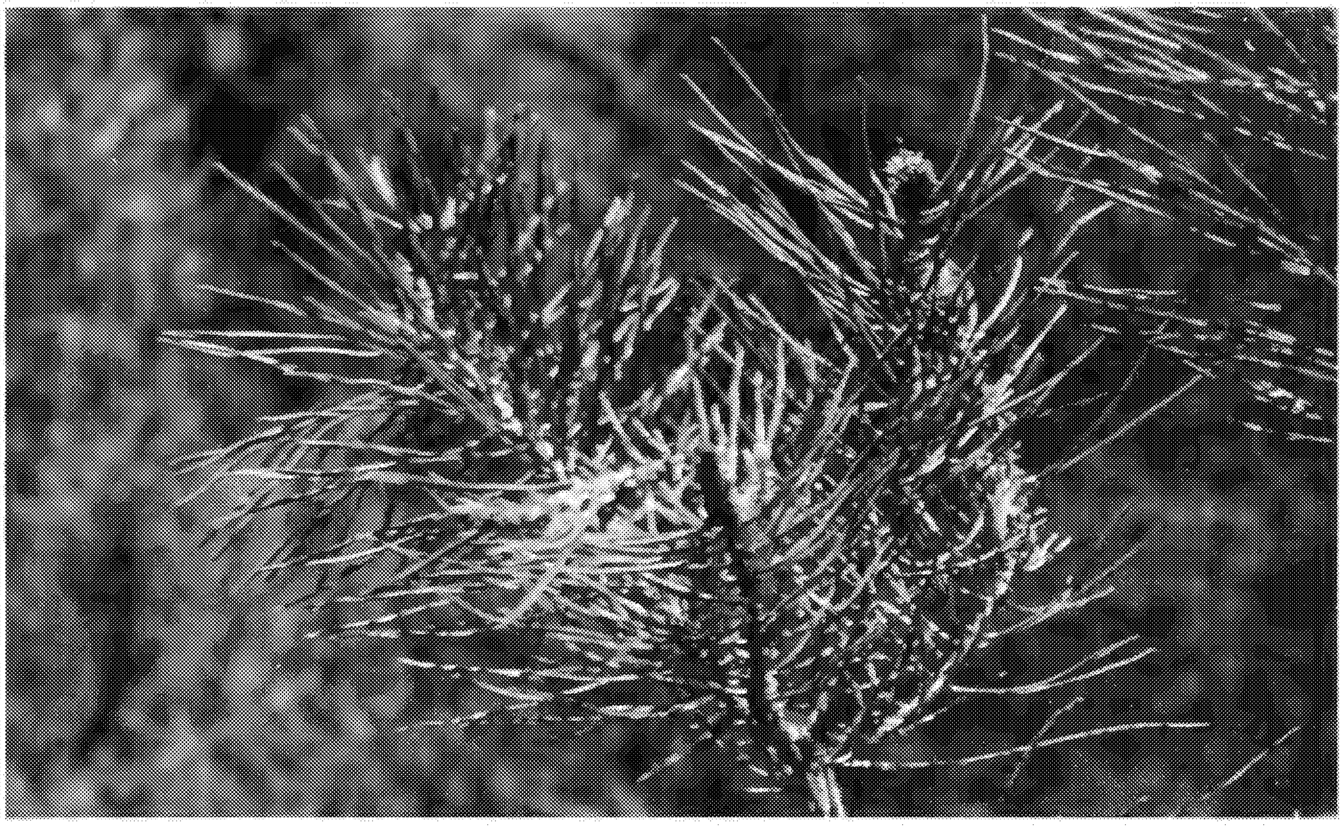

Figure 10. — (top) Severe foliar fluoride burn on lodgepole pine. This sample was collected in the 300 isopol zone on U. S. Forest Service land. XO.5

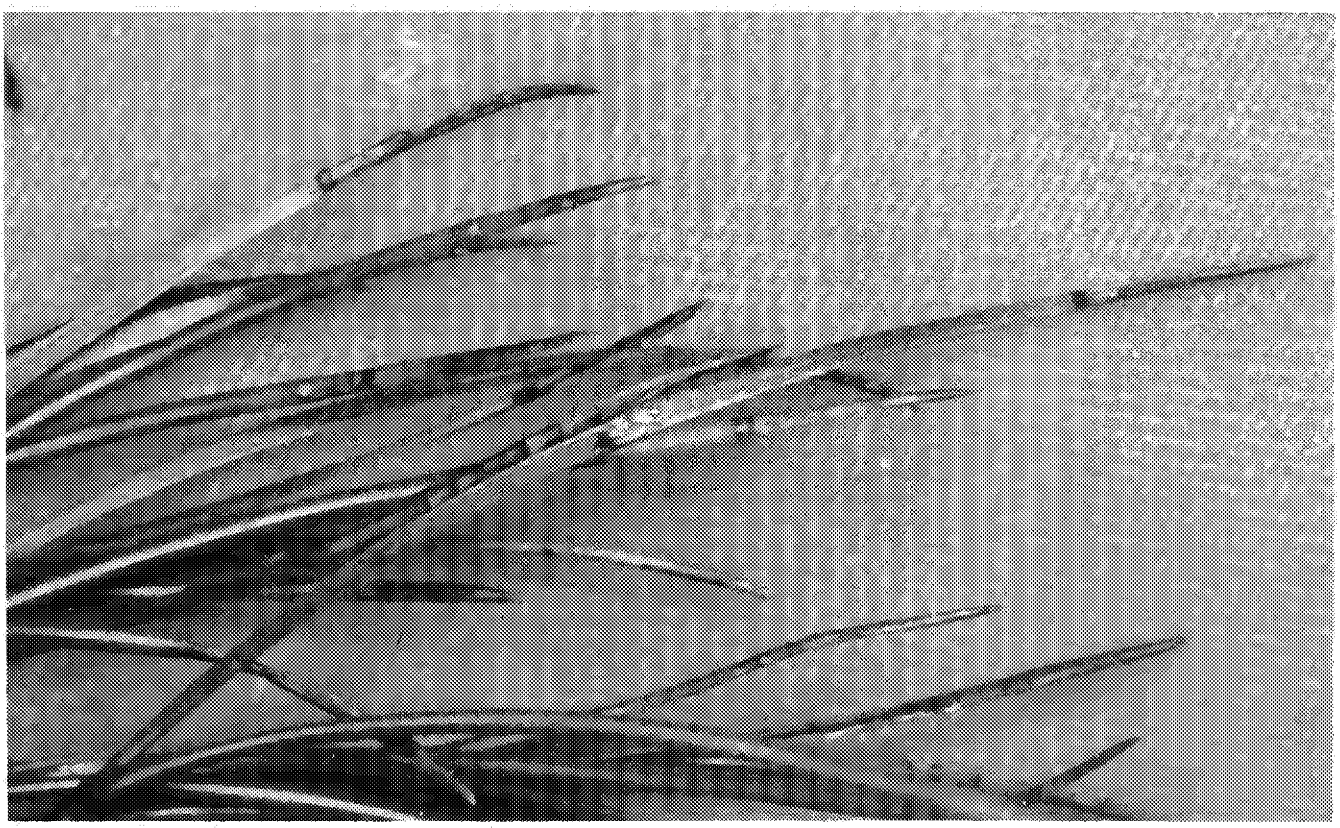

Figure 11. — (bottom) Closeup of fluoride burn on lodgepole pine collected from within the 300 isopol zone on U. S. Forest Service land. X2

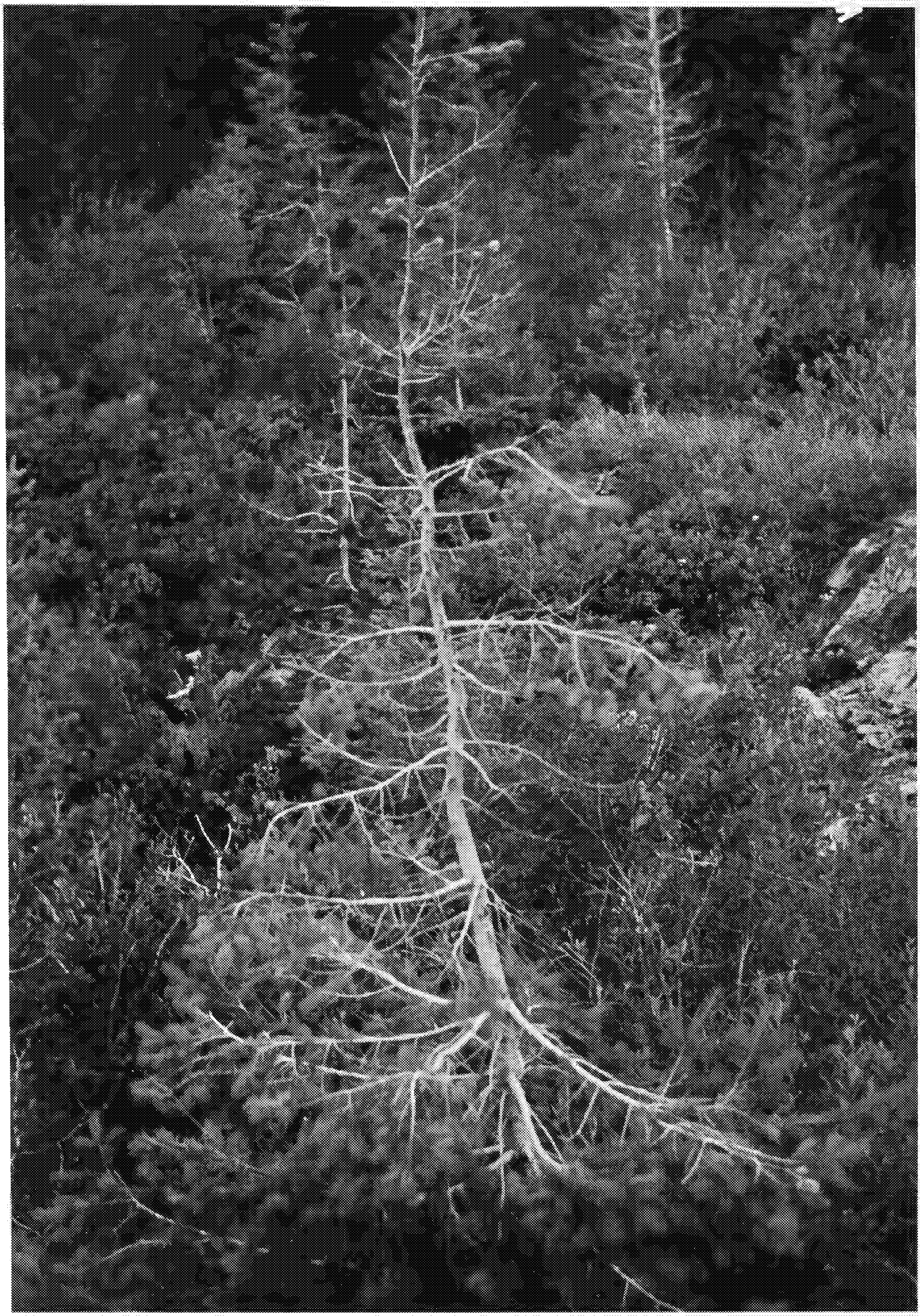

Figure 12. — Terminal dieback of Doublas-fir, caused by repeated fluoride fumigations. This tree is within the 300 isopol zone on Forest Service land. XO.5

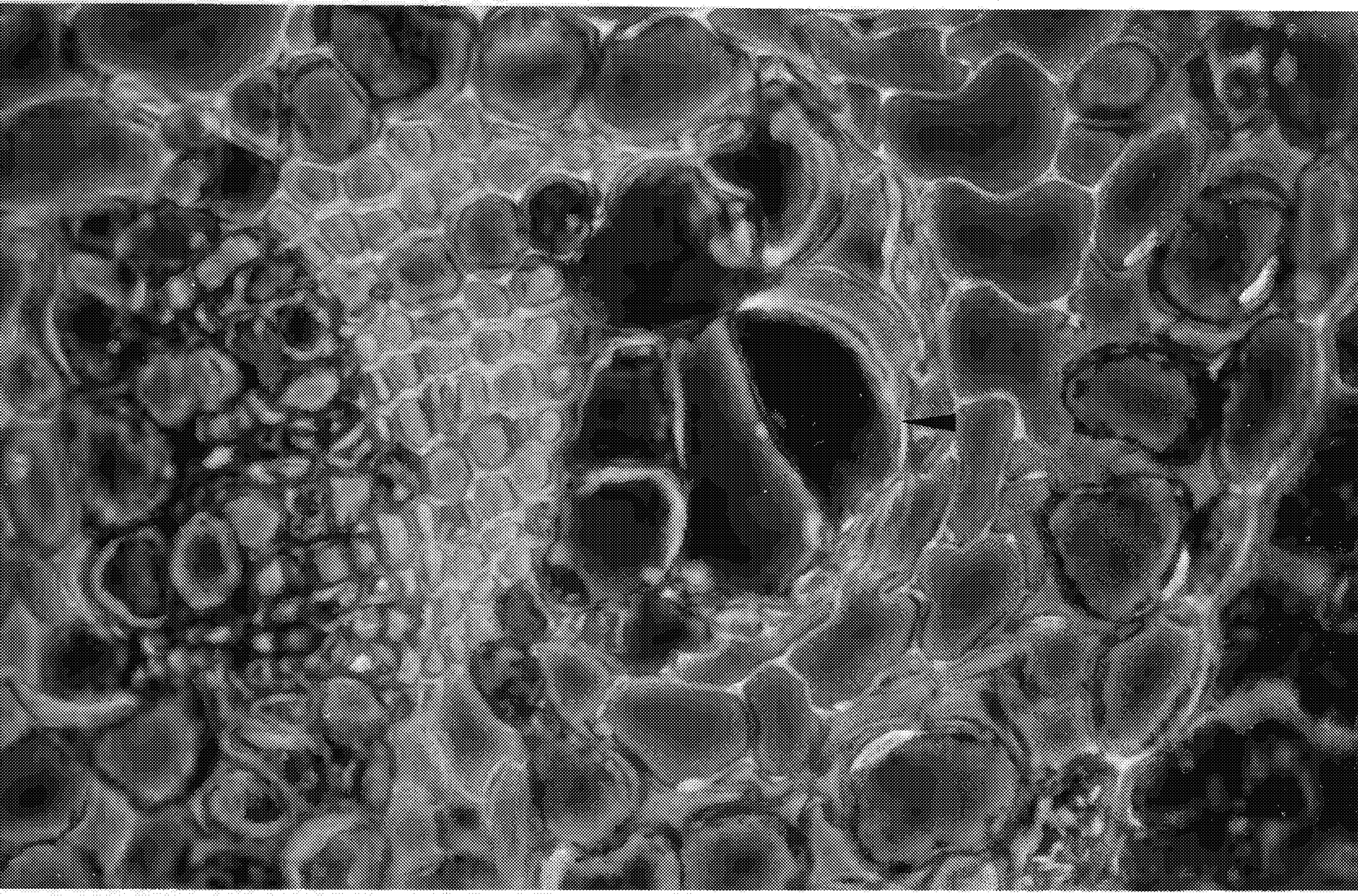

Figure 13. — Hypertrophied transfusion parenchyma cells and associated collapse of transfusion tracheids (arrow). Lodgepole pine. X350.

tioned at 9 micra thickness. Microscopic examination of conifer tissue in the early stage of necrosis (green-yellow part of transition zone) revealed that phloem and transfusion parenchyma and albuminous cells hypertrophied extensively, crushing and causing collapse of transfusion tracheids and phloem elements (figure 13). Enlarged nuclei were always associated with the hypertrophied cells and expanded nuclei often occurred in mesophyll cells (figure 14). Often the mesophyll cell immediately interior to the stomatal opening had been killed before fixation and sectioning. Epithelial tissue and nuclei hypertrophied extensively, often occluding resin canals (figure 15).

In the later stage of fluorosis (necrotic portion of transition zone), many of the hypertrophied cells had collapsed, leaving a void in the tissue. Granulosis of the chloroplasts in mesophyll cells was obvious.

This disease syndrome is unlike any caused by fungi or adverse weather conditions, and is very distinctive for fluorosis of conifer tissue. This type of internal injury caused by fluorides occurred generally within the isopols 30 ppm and greater, including vegetation in Glacier National Park, but varied depending on the species.

Aerial Photography

The aerial photography was scheduled to be completed by June 15, 1970. However, because of adverse weather, it was not done until mid-July, and much of the injury present on vegetation was masked by the new flush of growth. Even so, injury was detectable generally within the 60 ppm isopol. Mortality of conifers was readily identifiable within the 300 ppm isopol. Ektachrome Aero film was satisfactory for delineating general areas sustaining visual pollution injury.

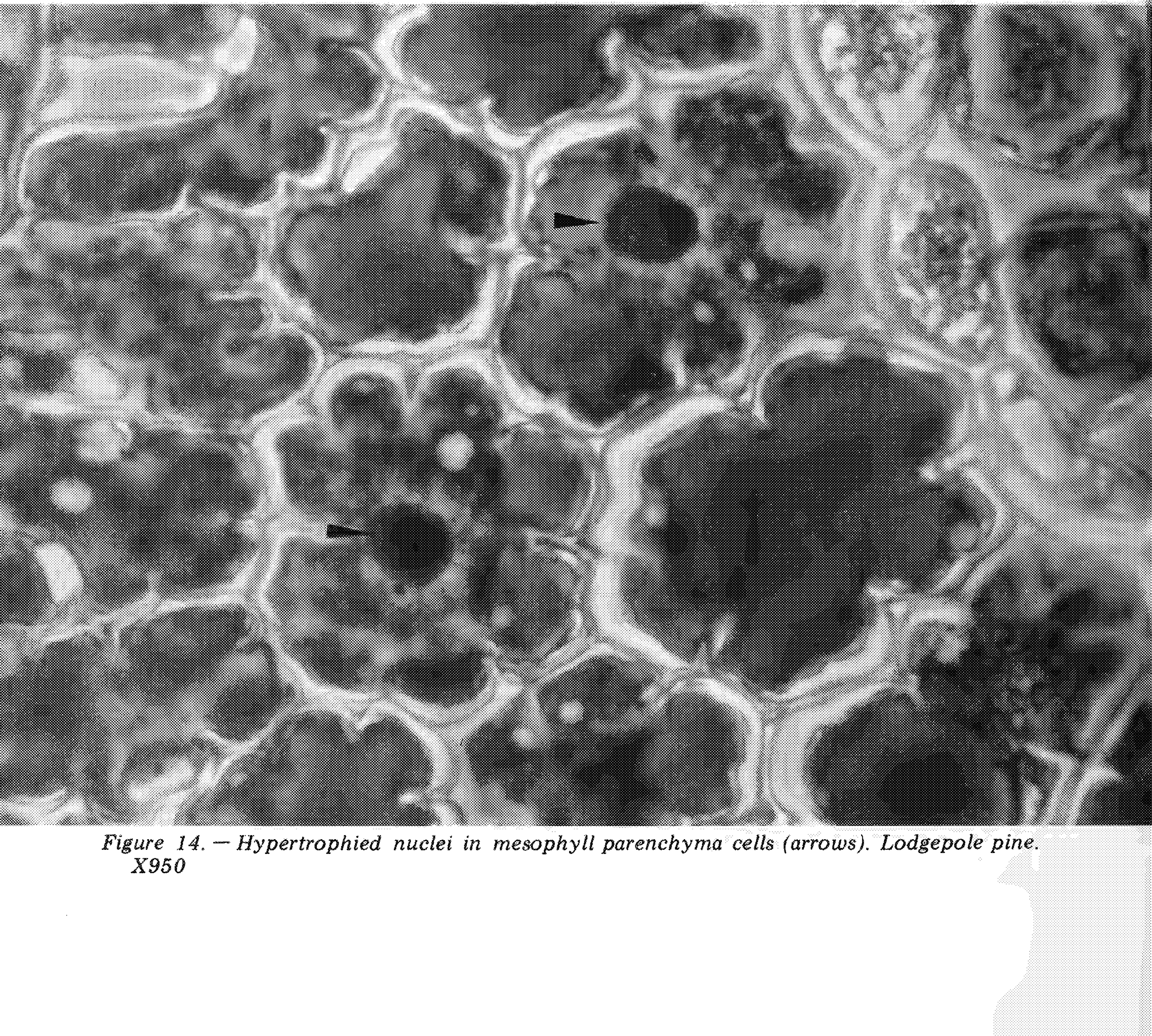

Figure 14. — Hypertrophied nuclei in mesophyll parenchyma cells (arrows). Lodgepole pine. X950

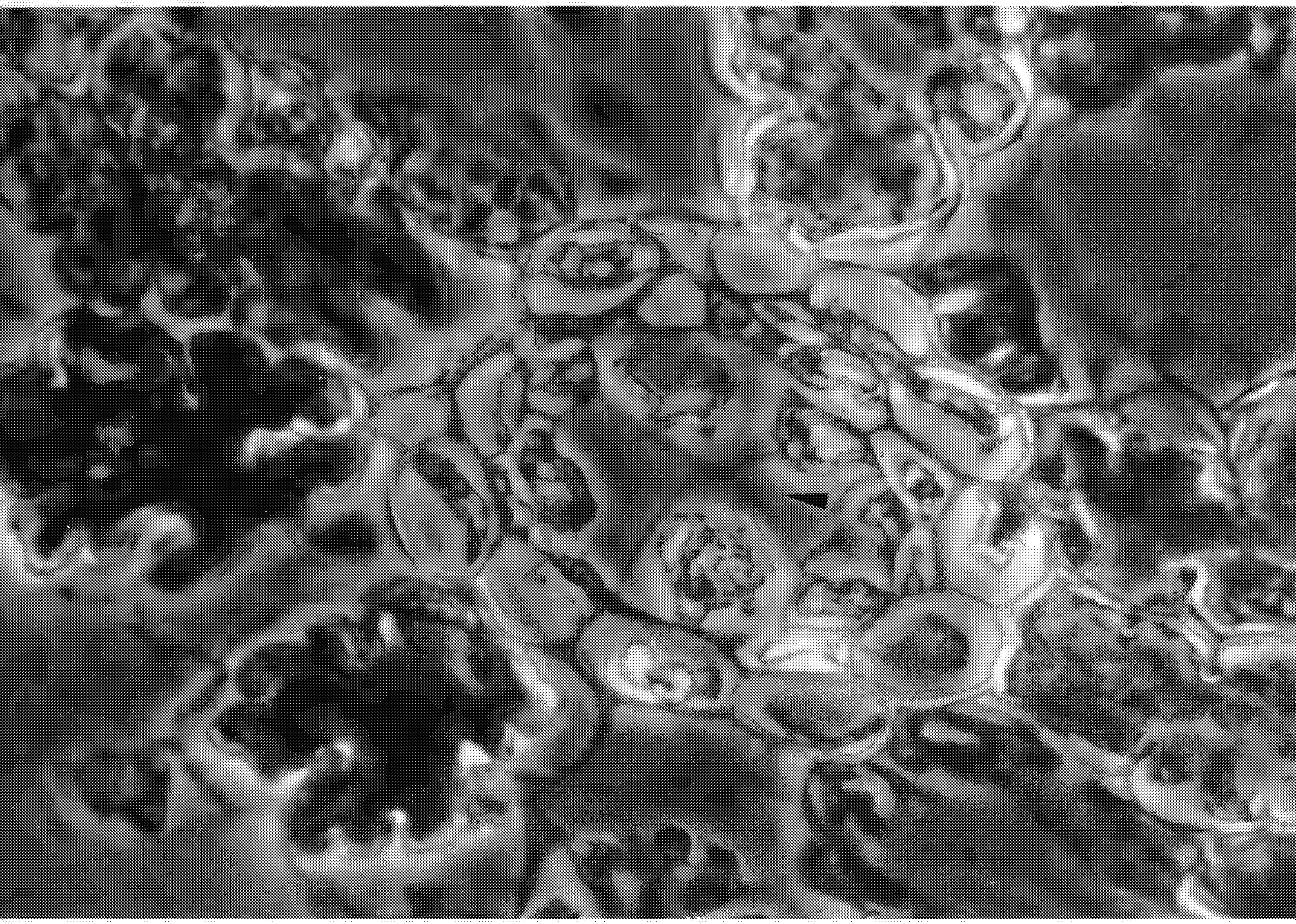

Figure 15. — Hypertrophied epithelial cells in ponderosa pine resin canal (arrow). X950.

Fluoride accumulation by Insects

Control Samples. Fluoride content data of control insects are given in Appendix VI. Foliage feeders were represented by larch casebearer at 16.5 ppm and grasshoppers at 7.5 ppm. Highest control for cambial feeders was 11.5 ppm found in *Ips* sp. Red turpentine beetle, also a cambial feeder, had 4.8 ppm fluoride. Bumblebees, which are pollinating insects, had 7.5 ppm and damselflies, which are predaceous, had 9.2 ppm fluoride.

Test Samples. Generally at least twice as much fluoride was found in test samples as in corresponding control samples. Foliage feeders collected within the areas sustaining fluoride pollution had from 21.3 to 48.6 ppm fluoride, with weevils containing the highest. From 8.5 to 52.5 ppm fluoride was found in the cambial feeding group, with engraver beetles sustaining the largest amount. The highest readings in the pollinating groups were found in bumblebees at 406 ppm and the lowest in the wood nymph butterfly at 58.0 ppm. Predaceous insects ranged from 6.1 to 170.0 ppm fluoride, with ants accumulating the largest amount.

Insect Population Sampling

Controls. Larch casebearers ranged from 0 - 27.6 per 100 spur shoots (Appendix VII).

Scale counts on lodgepole pine averaged 0.3 insects per 600 needles (Appendix VIII); on ponderosa pine they averaged 5 per 600 needles (Appendix IX).

Radial Collections. Of the possible sampling locations, only 30 plots had sufficient larch to sample larch casebearer populations; 34 plots had sufficient lodgepole pine to sample for scale insects; and 16 plots had sufficient ponderosa pine to sample for scales.

Because extensive sampling of vegetation for foliar fluoride analysis was done in the pathological phase, we did not feel it necessary to repeat vegetation collections on individual plots during this phase. Therefore, counts of casebearer and scale were compared to the fluoride readings from the respective plots in the pathological phase.

No discernible pattern existed from the larch casebearer samples (Appendix VII). Relatively high casebearer counts were found at all distances from the aluminum plant with the exception of one-fourth mile where the only larch sample taken had no casebearer.

Generally, scale counts on lodgepole pine decreased with increasing distance from the aluminum plant, with the exception of the 8-mile samples (Appendix VIII).

Scale counts on lodgepole pine were compared to foliar fluoride content of conifers on the same plot (Appendix X). Linear regression analysis showed no significant correlation ($r = 0.201$, 30 degrees of freedom) existed.

The regression line is shown in Figure 16. A constant increase in scale numbers with increasing fluoride concentrations is indicated. Although the correlation is insignificant, the graph does indicate a trend and more extensive sampling likely would confirm the relationship.

Lodgepole pine that had scale counts exceeding 50 per 600 needles contained 23 to 401 ppm fluoride (average 133 ppm) in all vegetation, compared to a range of 6 to 160 ppm fluoride (average 36 ppm) for pines with less than 50 scales per 600 needles.

The same pattern existed for the ponderosa pine samples (Appendix VIII) even though the number of samples was smaller.

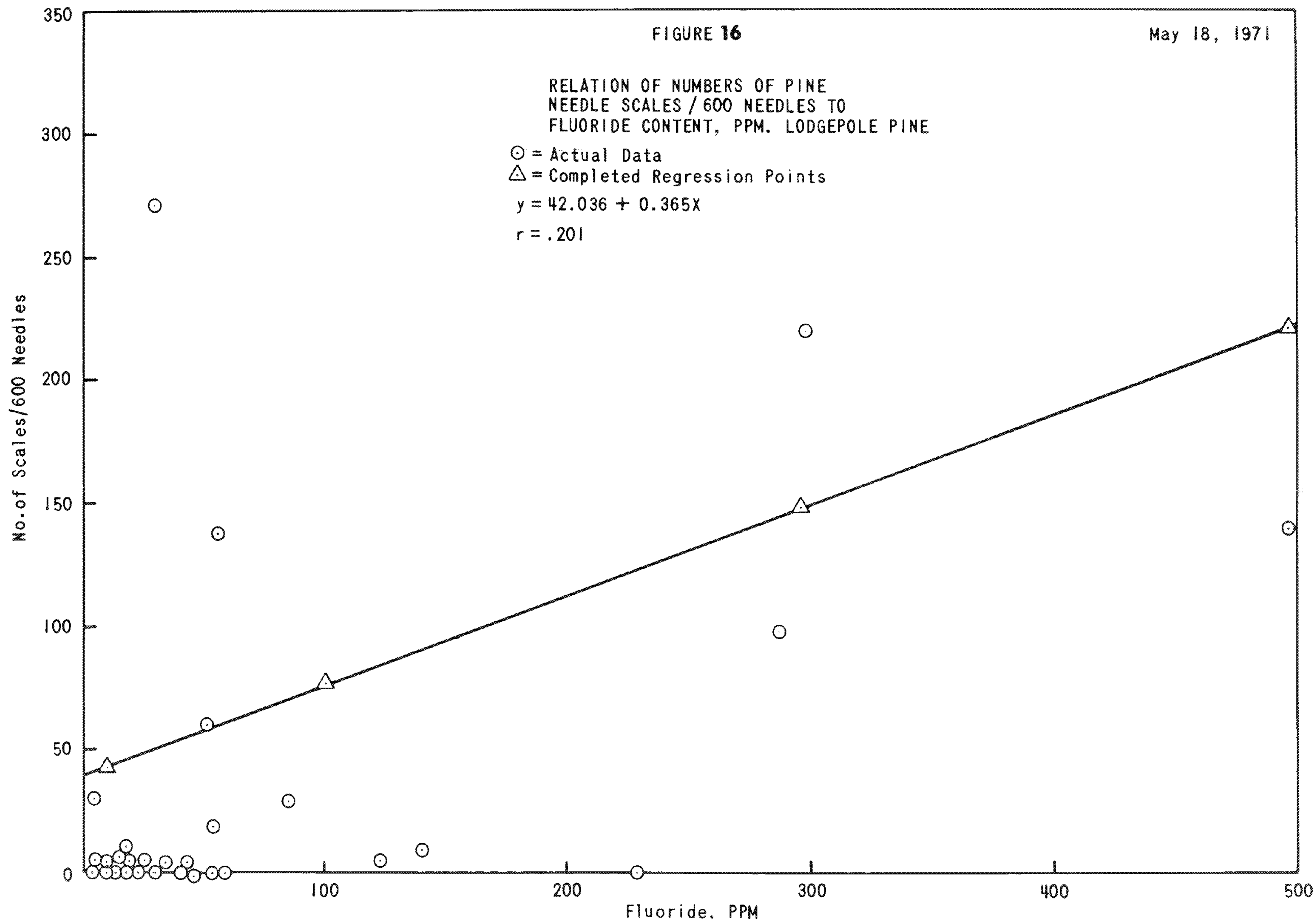

FIGURE 16

RELATION OF NUMBERS OF PINE NEEDLE SCALES / 600 NEEDLES TO FLUORIDE CONTENT, PPM. LODGEPOLE PINE

Discussion and Conclusions

General

The original objectives of the evaluation were satisfied. The chemical and histological analyses showed definitely that fluorides were the major factor contributing to injury and damage on vegetation peripheral to the aluminum reduction plant. That the source of the fluorides was the Anaconda Company's aluminum reduction plant is confirmed by the convergence of lines of increasing concentration at the reduction plant. Through systematic and special sampling systems, we were able to map the area affected by fluorides.

The 32 insect tissue samples analyzed showed definitely that fluorides accumulate in insects. Generally, scale insects increased with increasing concentrations of fluoride in lodgepole and ponderosa pine needle tissue; however, data was not complete. Larch casebearer populations showed no trends.

Rates of Accumulation

Previously we mentioned that the aluminum plant had reduced fluoride emissions from 7,600 to 5,000 pounds per day. One can hypothesize that a corresponding decrease in fluroide content of vegetation should occur. However, our data shows this is not universally true. In fact, only for the pine species under insidious levels of fumigation (10-60 ppm isopols) did the rate drop substantially. The rate of accumulation in firs did not change even at the insidious levels of fumigation. We interpret this as indicating the existence of a threshold concentration of atmospheric fluoride as measured by emission at the aluminum plant, below which a decreasing level of atmospheric fluoride results in a corresponding decrease in accumulation by plants and which, when exceeded, contributes little to the total accumulation by plants. This threshold effect could be realized either by short exposures to high concentrations of atmospheric fluorides or prolonged exposure to lower levels. The threshold level may be much lower than 5,000 pounds per day. Even at "low" levels of 500 to 1,000 pounds per day, injury to vegetation could be expected up to 3 or 4 miles from the aluminum plant, and even farther under stable inversion periods.

Possibly the threshold for pine species was reached somewhere between the 10-60 isopols, but was never reached for the firs and spruces. A possible explanation for this differential response between pines and firs is that pines are more sensitive to fluorides than are firs and spruces. Gordon (personal communication) has indicated that the physiological activity of a tree is directly related to its ability to accumulate fluorides. Thus pine trees sensitive to fluorides may accumulate fluorides rapidly up to a point, at which time phytotoxic effects result in a decrease in physiological activity and a corresponding decrease in fluoride accumulation rate. Because the fluoride concentration at which phytotoxicity occurs in firs and spruces may be higher than pines, their physiological activity would be greater and their ability to accumulate fluorides would continue beyond that of pines.

Susceptibility of Species

We noted apparent differences in fluoride susceptibility in terms of expression of visual burn symptoms by the plant. Of the conifers, white pines were most susceptible followed by ponderosa pine, lodgepole pine, and Douglas-fir, respectively. Spruces, western red cedar, and subalpine fir were most tolerant. Of the shrubs, chokecherry and serviceberry showed symptoms of fluorosis quite readily, with buffalo berry the most tolerant. Lily of the valley and disporum were highly sensitive compared to other forbs. These classifications are, however, based only on field data and observations.

Ecological Implications

Ecologically, western white pine is regarded as a seral or temporary species in the trend towards a climax community. This species occurs on the east side of Teakettle Mountain as an integral part of the forest community. However, it has been severely affected by fluorides, and in many cases is dying or dead. This unnatural selection most certainly is hastening the trend towards climax. The same sort of rational could also be made for lodgepole pine, for it too is affected by fluorides much more severely than subalpine fir and western red cedar. Certainly unnatural ecological changes are occurring in response to the fluoride pollution, are resulting in reduced biological diversity, and should receive considerable study in the future.

Pollution in Glacier National Park

Vegetation within 71,670 acres of Glacier National Park has accumulated, in quantities greater than 10 ppm, fluorides emitted from the reduction plant (Appendix III-B). On 9,600 acres, plants have accumulated 30 ppm or more, and some have been lightly injured. Plants on 371 acres showed average accumulations up to 60 ppm with some moderate injury on lodgepole, white, and ponderosa pines and Douglas-fir. As indicated by figure 8, most of the injury and high accumulation levels occurred on the southwest face of the Apgar Mountains and the southwest face of the Belton Hills. No samples were collected from the upper reaches of McDonald Creek in Glacier National Park. However, the isopol map does indicate the possibility of pollution damage near Logan Pass, and future sampling should include these areas.

Pollution in Coram Experimental Forest

All the special samples collected near Desert Mountain (Figure 3) were located within Coram Experimental Forest. Many studies important to management of western larch currently are in progress on the experimental forests. Generally, average fluoride accumulations in western white pine and western larch ranged from 10-25 ppm. Little foliar injury was found. We do not know what affect these insidious fluoride accumulations may have on reproductive potential, growth, and other factors of the species being studied. However, the presence of elevated fluorides may contribute to unexplained error in statistical analyses of the data.

Study Replicated

Data for construction of isopols and radial profiles displayed in this report were obtained from the second sampling period as these were more current. A similar pattern existed for data of the first sampling period but was not of the magnitude as that of the second. Because data of both sampling periods was collected in the same manner, each sampling period could be considered a replicate of the same experiment. As both sampling periods yielded data showing similar trends, the techniques used (i.e., radial sampling) are considered valid.

Insects and Fluoride

The damsel flies and ostomids are 100 percent predatory in both larval and adult stages. Fluoride accumulated in these insects must have come from the insects upon which they fed, indicating that fluoride is passed along the food chain to some predators.

In two instances where both larvae and adults of the same species (flatheaded beetles and ostomids) were analyzed, accumulation was much higher in the adults. Bumblebees collected in the summer had over twice the fluoride levels as those collected in the spring. Both cases suggest that accumulation occurs throughout the life of the insects.

Many plants are dependent upon insect pollinators for seed production. By altering the pollinator complex, i.e., bumblebees, honeybees, sphinx moths, and others, it is possible to alter vegetational types, and subsequently much of ecology of an area. Studies have shown fluorides to be devastating to honeybees. If this applies to pollinators in general it could have a detrimental effect on fruit trees, legumes, and many other insect-pollinated flowering plants in the polluted area.

Current research shows that several chemicals and pesticides (DDT, etc.) are adversely affecting organisms farther up the food chain. Eagles lay soft-shelled nonviable eggs due to feeding on fish containing high levels of DDT. Insects are one of the most important elements of the food chain. They are the only food of some birds, fish, amphibians, reptiles, mammals, and arthropods including other insects and arachnids. If fluorides accumulated by insects are injurious to insectivorous animals, then additional damage may be occurring.

It should be remembered that while there are many undesirable insects we would like to control, only about one in 100 is considered to cause significant crop loss. Much research is needed before the effect of different levels of atmospheric fluoride upon insect populations is clearly understood.

Fluroide has not been reported to be translocated in conifers, it is said to accumulate in the foliage by absorption. The bark beetle species examined feed solely as larvae and adults on the cambium of conifers. The high fluoride readings in some bark beetle samples indicate that fluorides are translocated in the xylem or phloem of the tree and are accessible to bark beetles.

Scale insects are known to build up on weakened or disturbed trees. Excessive dust alone can trigger scale outbreaks. There appears to be a relationship to scale populations and fluoride accumulated by the vegetation, but more extensive sampling is needed.

Economic and Esthetic Damage

The Forest Service is charged with the responsibility of wise use of all National Forest lands. We are also responsible for technical advise and service to National Parks, State and private concerns. The responsibilities are administered in five general use categories: 1) wildlife, 2) water, 3) forage, 4) recreation, and 5) timber. Therefore, an economic analysis of fluoride pollution would have to consider values in all these categories.

We have not yet made a thorough economic analysis of the fluoride pollution problem at Columbia Falls. Recreation and wildlife values are difficult to establish. Gordon[1] has shown that wildlife in the area is accumulating fluorides, but no economic loss has been established. Excessive fluoride concentrations in water have not yet been reported in the Columbia Falls area, and damage to the watershed through loss of ground cover likely is minimal.

Previous research has shown that livestock will develop fluorosis if feeding is done on vegetation containing more than 35 ppm fluoride. The area within the 30 isopol contains several thousand acres of grazing lands that should not be utilized, indicating a dollar value which can be fixed.

Research also has shown that diameter growth rates of conifers will decrease from 1-6 fold in fluoride polluted areas. We have not collected at Columbia Falls any data concerning growth decline of conifers. However, the decrease mentioned above could be applied to commercial species in the area.

Environmental damage is continuing and can be stopped only by (1) installation of efficient pollution abatement equipment at the reduction plant to limit fluoride emission to 0.0 pounds per day, which likely is impossible, or (2) closure of the plant. The latter is an unrealistic position because the aluminum plant does provide jobs to hundreds of people at a payroll exceeding $9 million per year. Therefore, it would seem appropriate to support the fluoride emission standard of 864 pounds per day set by the State of Montana.

If emissions are not reduced to the State standard, extensive pollution can be expected to continue. As a result, it would be unwise to raise livestock within the area included by the 30 ppm isopol. Leafy vegetables and fruits grown or collected within the 30 ppm isopol should be thoroughly washed before they are eaten.

Forest vegetation would continue to decline, and the southwestern portion of Glacier National Park would continue to sustain a chronic level of injury caused by excessive fluorides.

Future Plans

We are establishing a permanent system to monitor for fluoride pollution in the Columbia Falls area. The precise methods have not yet been outlined.

During the summer of 1971 we will evaluate possible timber growth losses due to fluoride. It is anticipated that a series of variable plots would provide the data, but definite procedures have not yet been established.

[1] *Personal communication with Dr. C. C. Gordon, University of Montana.*

Acknowledgements

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Appendix I

COMMON AND SCIENTIFIC NAMES OF PLANTS AND ANIMALS STUDIED OR REFERRED TO IN THIS REPORT

TREES

Common Name	Scientific Name
Western Larch	*Larix occidentalis* Nutt.
Western White Pine	*Pinus monticola* Dougl. ex. D.
Whitebark Pine	*Pinus albicaulis* Engelm.
Ponderosa Pine	*Pinus ponderosa* Laws.
Douglas-fir	*Pseudotsuga menziesii* (Mirbel) Franco
Lodgepole Pine	*Pinus contorta* var. *latifolia* Engelm.
Engelmann spruce	*Picea engelmannii* Parry ex Engelm.
Grand fir	*Abies grandis* (Dougl.) Lindl.
Western Red Cedar	*Thuja plicata* Donn. Hort.
Subalpine fir	*Abies lasiocarpa* (Hook.) Nutt.
Yew	*Taxus brevifolia* Nutt.
Juniper	*Juniperus occidentalis* Hook.

SHRUBS

Service berry	*Amelanchier alnifolia* Nutt.
Oregon grape	*Berberis repens* Lindl.
Ribes	*Ribes* sp. L.
Snowberry	*Symphoricarpos albus* (L). Blake
Ocean Spray	*Holodiscus discolor* (Pursh) Maxim.
Buffalo Berry	*Shepherdia argentea* (Pursh) Nutt.
Spiraea	*Spiraea betulifolia* Pall.
Paper Birch	*Betula papyrifera* Marsh.
Rose	*Rosa woodsii* Lindl.
Mountain maple	*Acer glabrum* Torr.
Willow	*Salix* sp. L.
Dogwood	*Cornus canadensis* L.
Cottonwood	*Populus trichocarpa* T. and G. ex Hook
Huckleberry	*Vaccinium* sp. L.

Common Name	Scientific Name
Mountain ash	*Sorbus scopulina* Greene
Ninebark	*Physocarpus malvaceus* (Greene) Kuntze
Aspen	*Populus tremuloides* Michx.
Alder	*Alnus incana* (L.) Moench
Chokecherry	*Prunus virginiana* L.
Red stem ceanothus	*Ceanothus sanguineus* Pursh
Evergreen Ceanothus	*Ceanothus velutinus* Dougl. ex Hook.
Pachistima	*Pachistima myrsinites* (Pursh) Raf.
Hawthorne	*Crataegus douglasii* Lindl.
Honeysuckle	*Lonicera ciliosa* (Pursh) DC.
Elderberry	*Sambucus cerulea* Raf.
Kinnikinnick	*Arctostaphylos uva-ursi* (L.) Spreng.
Syringa	*Philadelphus lewisii* Pursh
FORBS	
Lily of the Valley	*Smilacina stellata* (L.) Desf.
Lupine	*Lupinus* Sp. L.
Mullein	*Verbascum thapsus* L.
Heart Leaf Arnica	*Arnica cordifolia* Hook.
Strawberry	*Fragaria virginiana* Duchesne
Thimbleberry	*Rubus parviflorus* Nutt.
Fern	*Pteridium equilinum* (L.) Kuhn
Wild Snapdragon	*Antirrhinum* sp. L.
Hawkweed	*Hieracium* sp. L.
Fireweed	*Epilobium angustifolium* L.
Yarrow	*Anchillea millefolium* L.
Mint	*Mentha* sp. L.
Larkspur	*Delphinium* sp. L.
Arrow Leaf Balsam Root	*Balsamorhiza sagittata* (Pursh) Nutt.
Wild Pea	*Vicia sativa* L.
Devils Club	*Oplopanax horridum* (J. E. Smith) Miq.
Aster	*Aster* sp. L.
Meadow Rue	*Thalictrum occidentale* Gray
False Azalea	*Rhododendron* sp. L.
Bedstraw	*Galium* sp. L.
Goldenrod	*Solidago* sp. L.
Wild Onion	*Allium* sp. L.
Lousewort	*Pedicularis* sp. L.
Canadian Thistle	*Cirsium arvense* L. (Scop.)
Disporum	*Disporum hookeri* (Torr.) Nicholson
Absinthium	*Artemisia absinthium* L.
Raspberry	*Rubus idaeus* L.
Pussytoes	*Antennaria* sp. Gaertn.
Michaux sagebrush	*Artemesia michauxiana* Bess.
Hounds Tongue	*Cynoglossum officinale* L.
Alum Root	*Heuchera* sp. L.
Dogbane	*Apocynum androsaemifolium* L.

GRASSES

Common Name	Scientific Name
Pine Grass	*Calamgrostis rubescens* Buckl.
Bear Grass	*Xerophyllum tenax* (Pursh) Nutt.
Timothy Grass	*Phleum* sp. L.
Cheat Grass	*Bromus tectorum* L.
Blue Grass	*Poa* sp. L.

INSECTS

Black pine leaf scale	*Nuculaspis californica* (Coleman)
Desert Locust	*Schistocera gregaria* (Forsk.)
Yellow Meal Worm	*Tenebrio molitor* (L.)
Larch casebearer	*Coleophora laricella* (Hbn.)
Pine Needle Scale	*Phenacaspis pinifoliae* (Fitch)
Sugar pine tortrix	*Choristoneura lambertiana* (Busck)
Needle Sheath Miner	*Zellaria hambachi* Busck
Needle Miner	*Recurvaria* sp.
Bumblebee	*Bombus* sp.
Sphinx moth	*Hemaris* sp.
Honey bee	*Apis mellifera* Linn.
Skipper butterfly	*Erynnis* sp.
Wood nymph	*Cercyonis* sp.
Weevils	*Magdalis* sp.
Grasshoppers	*Melanoplus* sp.
Cicadas	Family *Cicadidae*
Engraver beetles	*Ips* sp. DeGeer
Buprestid larvae	*Melanophila* sp.
Buprestid adults	*Melanophila* sp.
Red Turpentine Beetle	*Dendroctonus valens* LeConte
Douglas-fir Beetle	*Dendroctonus pseudotsugae* Hopk.
Ants	Family *Formicidae*
Ostomids	*Temnochila* sp.
Damsel Flies	*Argia* sp.
Longlegged fly	*Medeterus* sp.
Cerambycids	Family *Cerambycidae*
Elaterids	Family *Elateridae*

MAMMALS

Columbian-ground squirrel	*Spermophilus columbianus columbianus* Ord.
Grizzly Bear	*Ursus horribilis* Merriam
Elk	*Cervus canadensis Nelsoni* Bailey

Appendix II-A

TABULATION OF RADIAL AND CONTROL DATA
First Sampling

	Average Fluoride Content						I. I.	
		Conifers				Grand	Ave	High
Plot#	Shrubs	1969	1970	Herbs	Grasses	Ave	I. I.	I. I.
Control #1	5.65[1]	6.25	9.25	6.67	--	6.92	.003	.006
Control #2	5.0	3.5	7.5	5.0	1.3	4.79	0.0	0.0
Control #3	11.4	7.58	6.28	10.0	9.8	8.02	0.0	0.0
Control #4	7.5	10.0	11.0	8.5	8.5	10.36	0.0	0.0
Control #5	7.17	4.75	6.77	12.0	--	7.03	.007	.014
Control #6	4.77	6.33	3.00	5.50	16.0	5.80	.005	.006
R1-P1[2]	108.5	300	40.8	188	70.0	122.36	.138	.235
R1-P2	106.5	107.8	18.3	--	45.0	70.72	.305	.442
R1-P3	48.8	42.2	11.4	--	18.8	31.94	.044	.090
R1-P4	19.8	18.3	14.7	12.5	2.5	15.46	.132	.301
R1-P5	17.0	--	--	16.0	8.0	12.88	0.0	0.0
R1-P6	3.0	12.5	9.0	--	4.0	8.94	0.0	0.0
R1-P7	6.3	5.8	9.3	--	4.0	6.80	0.0	0.0
R2-P1	42.4	143.5	17.5	93.8	66.3	91.21	.075	.313
R2-P2	112.7	127.5	20.0	90.0	83.3	89.59	.196	.528
R2-P3	44.3	77.9	17.8	50.0	49.0	50.21	.163	.313
R2-P4	13.2	20.7	8.83	--	13.0	14.71	.079	.200
R2-P5	13.0	9.5	17.3	9.0	32.0	15.86	.012	.019
R2-P6	3.6	5.5	2.3	5.5	2.5	3.70	0.0	0.0
R2-P7	7.1	8.9	9.2	7.3	6.0	8.13	.004	.008

[1] *Fluoride content, ppm, dry weight basis*
[2] *R = Radius No., P = Plot No.*

APPENDIX II-A, Con't

Plot#	Shrubs	Conifers 1969	Conifers 1970	Herbs	Grasses	Grand Ave	Ave I. I.	High I. I.
	Average Fluoride Content						*I. I.*	
R3-P1	1166.6	--	--	875.5	775	1004.3	.020	.027
R3-P2	488	637	229	315	344	411.3	.107	.271
R3-P3	149.0	--	--	115	3.0	118.6	.009	.021
R3-P4	100.0	96.0	16.0	--	82.5	78.90	.136	.136
R3-P5	37.2	31.5	11.5	--	22.5	26.31	.066	.334
R3-P6	10.0	10.8	10.9	--	2.1	9.23	0.0	0.0
R3-P7	14.5	7.0	8.0	3.3		8.20	0.0	0.0
R4-P1	704.2	--	--	628.0	156	604.14	.025	.076
R4-P2	778.0	--	--	450.5	231	537.60	.010	.063
R4-P3	425.5	681.5	116.5	525	206	397.25	.072	.500
R4-P4	120.0	198.4	65.1	96.5	234	130.23	.150	.470
R4-P5	21.2	57.2	15.3	34.5	49.0	38.16	.066	.215
*R4-P6	14.0	9.77	7.50	10.0	13.0	10.13	.003	.007
*R4-P7	13.7	17.8	6.83	17.8	--	13.25	.038	.051
*R4-P8	15.4	18.0	7.15	9.9	103	19.68	.003	.003
*R4-P9	8.0	11.2	6.0	15.5	71.5	16.98	0.0	0.0
*R4-P10	9.27	8.93	4.0	5.7	5.8	6.88	.008	.008
R5-P1	1719	--	--	1038	250	1181.5	.288	.580
R5-P2	653	--	--	375	600	597.8	.029	.029
R5-P3	173.7	341.0	45.0	281	444	224.2	.197	.343
R5-P4	137.5	243.7	68.6	70.0	87.5	130.7	.086	.392
R5-P5	25.0	45.9	9.60	22.5	6.0	27.80	.151	.344
R5-P6	20.0	30.2	12.7	--	21.0	19.93	.007	.023
R5-P7	16.3	30.5	--	11.5	23.5	19.60	.003	.006
*R5-P8	20.50	19.15	10.2	21.0	26.0	17.43	.006	.011
*R5-P9	20.25	29.75	11.0	13.5	72.5	24.33	.115	.115
*R5-P10	11.05	10.1	4.10	8.28	5.5	7.46	0.0	0.0
R6-P1	--	1950	--	363	313	875.3	.202	.442
R6-P2	1125.3	--	--	431	581	877.6	.019	.089
R6-P3	115.3	292	29.8	163	68.8	138.2	.019	.083
R6-P4	57.0	85.0	33.0	63.3	36.0	51.17	.106	.209
R6-P5	33.8	20.6	7.5	29.2	24.5	23.0	.073	.146
R6-P6	17.1	37.5	8.5	20.8	37.0	21.4	0.0	0.0
R6-P7	7.5	19.0	10.5	11.0	15.0	11.75	0.0	0.0
*R6-P10	14.65	13.5	6.0	18.5	51.5	17.83	0.0	0.0
R7-P1	1073	--	--	600	338	871.7	.065	.299
R7-P2	881.3	--	--	103	233	596.0	.118	.230

APPENDIX II-A, Con't

	Average Fluoride Content						I. I.	
		Conifers				Grand	Ave	High
Plot#	Shrubs	1969	1970	Herbs	Grasses	Ave	I. I.	I. I.
R7-P3	65.3	168	22.3	62.5	75.0	68.67	.091	.225
R7-P4	55.0	111.0	18.9	44.0	44.0	63.20	.058	.111
R7-P5	25.3	--	--	25.5	42.0	29.50	0.0	0.0
R7-P6	4.8	16.2	5.3	14.0	20.5	10.87	.016	.029
R7-P7	17.3	10.0	4.5	7.0	21.0	12.43	0.0	0.0
R8-P1	399.8	975	175	--	110	409.8	.052	.115
R8-P2	129	245	136.5	235	65.0	152.3	.016	.046
R8-P3	83.3	119.8	22.5	150	--	85.9	.176	.400
R8-P4	25.3	49.0	12.7	41.5	14.3	29.4	.087	.152
R8-P5	20.0	31.8	9.8	14.0	8.0	17.2	.018	.049
R8-P6	21.5	14.9	16.0	18.3	--	17.8	0.0	0.0
R8-P7	11.8	14.2	9.2	13.3	22.5	12.6	.016	.018
R9-P1	108.7	110	39.5	51.5	41.0	70.97	.026	.026
R9-P3	26.1	--	10.0	15.0	13.5	20.40	0.0	0.0
R9-P4	43.4	68.7	24.0	--	23.5	45.31	.005	.005
R9-P5	12.5	7.8	11.0	--	6.0	9.80	0.0	0.0
R9-P6	11.4	9.3	5.37	6.5	9.5	7.72	0.0	0.0
R9-P7	5.6	9.0	10.3	25.0	5.0	9.98	0.0	0.0
R10-P1	76.5	133	42.5	31.0	38.5	66.3	.032	.097
R10-P2	43.3	61.0	14.5	45.0	22.5	38.2	.070	.091
R10-P3	23.3	28.8	6.3	20.8	8.5	18.9	.013	.022
R10-P4	22.8	20.8	9.3	--	16.0	16.82	.054	.054
R10-P5	15.0	23.9	7.8	10.0	7.5	15.0	0.0	0.0
R10-P6	11.4	11.5	10.8	--	10.0	10.8	.003	.003
R10-P7	6.8	9.2	3 5	11.0	6.5	7.54	0.0	0.0

* — *Located on Glacier National Park lands.*

Appendix II-B

TABULATION OF RADIAL AND CONTROL DATA
Second Sampling

	Average Fluoride Content						I.I.	
		Conifers				Grand	Ave	High
Plot#	Shrubs	1969	1970	Herbs	Grasses	Ave	I. I.	I. I.
Control #1	8.7	8.5	4.5	10.0	11.5	8.67	0.0	0.0
Control #2	6.8	7.0	5.8	10.5	5.5	6.88	0.0	0.0
Control #3	15.8	11.3	4.75	6.5	7.5	7.91	0.0	0.0
Control #4	10.9	5.9	5.2	17.0	17.0	9.74	0.0	0.0
Control #5	10.5	7.8	5.2	--	16.0	8.50	0.0	0.0
Control #6	5.7	6.0	4.8	10.0	12.5	6.46	0.0	0.0
R1-P1	323	338	115	310	139	258	.079	.086
R1-P2	140.5	131.7	38.9	115	102	95.3	.052	.143
R1-P3	65.5	40.7	19.3	32.0	20.0	40.9	.003	.003
R1-P4	43.3	18.5	12.8	43.5	20.5	23.4	.024	.024
R1-P5	11.5	9.0	6.0	--	5.0	8.60	0.0	0.0
R1-P6	13.8	9.10	6.2	--	--	9.06	0.0	0.0
R1-P7	9.0	4.5	5.5	--	5.0	5.90	0.0	0.0
R2-P1	136	189	64.7	61.5	93.5	111.0	.063	.093
R2-P2	147.5	100.8	26.8	146	44.5	92.6	.211	.279
R2-P3	110.0	124.7	32.8	104	32.0	85.3	.093	.104
R2-P4	29.1	17.3	8.5	--	18.5	22.2	0.0	0.0
R2-P5	16.0	16.0	9.5	14.5	--	13.6	.018	.032
R2-P6	9.0	9.3	8.5	16.0	8.8	9.48	0.0	0.0
R2-P7	9.8	8.5	5.5	8.8	4.5	7.84	0.0	0.0

APPENDIX II-B, Con't

	Average Fluoride Content						I.I.	
		Conifers				Grand	Ave	High
Plot#	Shrubs	1969	1970	Herbs	Grasses	Ave	I. I.	I. I.
R3-P1	1194	488	258	794	600	754.7	.281	.348
R3-P2	475	496.5	367.8	463	101	401.2	.313	.628
R3-P3	281.5	294.5	70.0	137	168	199.6	.156	.313
R3-P4	130	85.5	23	107	68	90.6	.034	.043
R3-P5	49.8	42.8	17.5	36.5	31.5	33.9	.014	.025
R3-P6	15.0	11.8	7.5	5.5	12.5	11.0	.008	.015
R3-P7	7.3	12.5	10.0	7.5	4.5	8.2	0.0	0.0
R4-P1	925	--	--	1250	469	903.2	--	--
R4-P2	1244	--	--	638	205	832.8	--	--
R4-P3	900.5	390.3	87.5	363	385	432.8	.208	.495
R4-P4	211.5	286.3	123.2	375	153	215.8	.119	.301
R4-P5	47.5	53.3	22.2	11.5	20.0	35.3	.075	.211
*R4-P6	32.5	11.7	9.3	15.5	--	17.5	0.0	0.0
*R4-P7	21.3	11.0	9.7	23.5	14.5	15.3	.007	.007
*R4-P8	37.8	22.3	8.0	13.5	--	20.0	.003	.003
*R4-P9	14.3	9.8	6.3	10.5	51.5	15.3	0.0	0.0
*R4-P10	10.5	6.2	6.1	5.5	4.3	6.3	.005	.005
R5-P2	1300	--	--	875	200	918.7	--	--
R5-P3	294.5	537.5	80.3	--	508	332.2	.132	.250
R5-P4	202.5	228.7	55	111	128	160.0	.063	.114
R5-P5	59.5	56.5	23.3	270	51.0	66.91	.014	.014
R5-P6	38.0	35.0	11.7	59.5	32.0	30.3	.003	.003
R5-P7	39.0	28.5	10.0	34.0	19.5	28.3	0.0	0.0
*R5-P8	73.0	18.0	13.0	--	23.5	24.5	0.0	0.0
*R5-P9	69.0	24.8	14.2	32.5	22.0	26.9	.014	.019
*R5-P10	12.8	11.9	10.2	9.0	15.5	11.6	0.0	0.0
R6-P1	1433	1728	775	2100	469	1339	.150	.150
R6-P2	1889	--	--	3000	488	1831	--	--
R6-P3	169.5	239.6	44.7	171	117	148	.114	.144
R6-P4	64.2	140	76.3	113	53.0	83.8	.182	.291
R6-P5	67.3	27.0	10.3	47.0	27.5	36.7	.006	.006
R6-P6	54.0	32.5	13.8	14.0	21.0	32.2	0.0	0.0
R6-P7	14.8	18.8	9.8	23.5	27.5	17.2	0.0	0.0
*R6-P10	20.5	18.5	9.3	30.5	154	30.9	0.0	0.0
R7-P1	1509	--	--	700	375	1120	--	--
R7-P2	969	1825	413	56.0	293	754.2	.289	.567

** — Located on Glacier National Park lands.*

APPENDIX II-B, Con't

	Average Fluoride Content						I. I.	
		Conifers				Grand	Ave	High
Plot#	Shrubs	1969	1970	Herbs	Grasses	Ave	I. I.	I.I.
R7-P3	154.5	142.5	31.3	143	160	120.0	.105	.154
R7-P4	100.5	104.7	17.5	—	63.5	76.7	.064	.064
R7-P5	47.3	51.5	20.5	28.5	16.5	25.3	.042	.042
R7-P6	35.0	37.8	18.9	25.0	13.0	26.2	.004	.005
R7-P7	23.0	14.0	10.2	17.2	7.5	14.3	.002	.002
R8-P1	812.5	906	306	750	131	619.7	0.0	0.0
R8-P2	475.5	313	209.5	325	70.0	269.9	0.0	0.0
R8-P3	199.0	167.0	41.3	250	97.5	145.2	.042	.067
R8-P4	48.5	56.0	55.3	32.5	—	49.3	0.0	0.0
R8-P5	33.5	28.1	14.5	31.5	14.5	24.1	0.0	0.0
R8-P6	26.3	15.5	8.8	14.5	42.5	19.5	0.0	0.0
R8-P7	16.2	14.0	8.50	—	12.5	12.7	0.0	0.0
R9-P1	251.5	168	76	198	85	171.7	0.0	0.0
R9-P2	134.7	—	—	113	132	129.8	—	—
R9-P3	45.0	19.3	12.3	52.5	35.0	30.1	0.0	0.0
R9-P4	68.0	41.5	14.0	35.8	33.0	39.0	0.0	0.0
R9-P5	9.0	4.5	4.75	8.5	6.0	5.79	0.0	0.0
R9-P6	17.3	4.7	4.27	14.0	—	9.48	0.0	0.0
R9-P7	10.5	4.0	6.03	—	5.5	6.29	0.0	0.0
R10-P1	185.5	140	62.0	200	76.0	141.5	.030	.030
R10-P2	107.7	51.5	23.5	77.5	72.5	78.3	0.0	0.0
R10-P3	30.7	23.0	8.8	26.0	28.5	24.6	0.0	0.0
R10-P4	41.8	16.5	15.5	31.0	24.0	26.6	0.0	0.0
R10-P5	9.5	20.8	10.5	33.8	12.5	17.41	.004	.004
R10-P6	—	12.3	5.0	—	11.0	10.1	0.0	0.0
R10-P7	—	4.7	4.4	7.0	8.0	5.74	0.0	0.0

Appendix III-A

AREA POLLUTED BY FLUORIDES, ALL LANDS STUDIED

	Within Radial System				Outside Radial System[1]				Total			
	Area Greater[2]		Area Between Isopols[3]		Area Greater		Area Between Isopols		Area Greater		Area Between Isopols	
Isopol	Sq. Miles	Acres	Sq. Miles	Acres	Sq. Miles	Acres	Sq. Miles	Acres	Sq. Miles	Acres	Sq. Miles	Acres
10	222	142,080			112	71,680			334	213,760		
			48	30,720			14	8,960			62	39,680
15	174	111,360			98	62,720			272	174,080		
			63	40,320			18	11,520			81	51,840
20	111	71,040			80	51,200			191	122,240		
			39	24,960			44	28,160			83	53,120
30	72	46,080			36	23,040			108	69,120		
			52	33,280			25	16,000			77	49,280
60	20	12,800			11	7,040			31	19,840		
			12	7,680			8	5,120			20	12,800
100	8	5,120			3	1,920			11	7,040		
			6	3,840							9	5,760
300	2	1,280			--	--			2	1,280		
			1	640							1	640
600	1	640			--	--			1	640		

1 — *The area Southwest of Columbia Falls.*
2 — *Total area sustaining greater than a given level of fluoride, p.p.m.*
3 — *Area between established Isopols, i.e., the area between the 10 and 15 Isopols, etc.*

Appendix III-B

AREA POLLUTED BY FLUORIDES
GLACIER NATIONAL PARK[1]

Isopol	Area Greater		Area Between Isopols	
	Sq. Miles	Acres	Sq. Miles	Acres
10	112	71,670		
			40	25,600
15	72	46,080		
			40	25,600
20	32	20,480		
			17	10,880
30	15	9,600		
			14.42	9,229
60	.58	371		

[1] *All lands studied in Glacier National Park were within the radial system.*

Appendix IV

FLUORIDE CONTENT AND INJURY INDEX VALUES FOR SPECIAL SAMPLES

Area	Sample Number	Species	Year of Foliage	Fluoride, PPM First Sampling	Fluoride, PPM Second Sampling	I.I. First Sampling	I.I. Second Sampling
	1*[1]	Larch	69	220		--[2]	--
	2*	Ponderosa Pine	69	40		--	--
	3*	Ponderosa Pine	68	175		--	--
	4*	Lodgepole Pine	69	85		--	--
	5*	Lodgepole Pine	68	290		--	--
	6*	Ponderosa Pine	68	155		--	--
Columbia	7*	Norway Maple	69	150		--	--
Falls	2a*	Lodgepole Pine	69	53.5		--	--
	2b*	Lodgepole Pine	68	71.0		--	--
	3a*	Lodgepole Pine	69	69		--	--
	3b*	Lodgepole Pine	68	60		--	--
	15a*	Ponderosa Pine	69	1.0		--	--
	15b*	Ponderosa Pine	68	29.5		--	--
Columbia	12a*	Lodgepole Pine	69	19.0		--	--
Mountain	12b*	Lodgepole Pine	68	86.5		--	--
	14a*	Douglas-fir	69	31.5		--	--
	14b*	Douglas-fir	68	43.0		--	--
	3	Lily of Valley	70	25.5		0.340	--
	4	Douglas-fir	70	12.0	16.0	0.011	0.00
		Douglas-fir	69	31.0	33.5	0.008	0.00
	5	Ponderosa Pine	70	--	13.0	--	0.00

[1] *Samples with an * were collected in 1969. No measurement of injury index was done on them. All other samples were collected in 1970.*
[2] *Samples not collected or processed.*

APPENDIX IV, Con't.

Area	Sample Number	Species	Year of Foliage	Fluoride, PPM First Sampling	Fluoride, PPM Second Sampling	I.I. First Sampling	I.I. Second Sampling
		Ponderosa Pine	69	--	35.5	--	0.16
	6	Ponderosa Pine	70	6.3	17.0	0.00	0.00
		Ponderosa Pine	69	41.3	45.5	0.122	.003
Teakettle Mountain	20	Lodgepole Pine	70	20.5	23.0	0.00	0.098
		Lodgepole Pine	69	120.0	139	0.512	0.005
	21	White Pine	70	24.5	52.0	0.00	0.007
		White Pine	69	118.0	158	0.229	0.216
	22	Ceanothus	70	190	--	0.137	--
	23	Douglas-fir	70	45.5	145	0.269	0.150
		Douglas-fir	69	--	500	--	1.105
	24	Ponderosa Pine	70	30.5	--	0.123	--
		Ponderosa Pine	69	124	--	0.721	--
	25	Lodgepole Pine	70	44.0	91.0	0.000	0.179
		Lodgepole Pine	69	300	781	0.193	0.326
	26	*Ribes* Sp.	70	563	--	0.301	--
	27	Douglas-fir	70	86.0	125	0.259	0.00
		Douglas-fir	69	--	481	--	0.00
		Douglas-fir	68	1163	--	0.010	--
	28	Pine Grass	70	438	14.0	--	--
	29	Ceanothus	70	450	244	0.092	--
	30	Lodgepole Pine	70	26.0	13.5	0.002	0.00
		Lodgepole Pine	69	92.5	58.0	0.081	0.014
	31	White Pine	70	16.8	77.5	0.000	0.000
		White Pine	69	99.0	117	0.001	0.000
	32	Lodgepole Pine	70	11.0	22.0	0.000	0.101
		Lodgepole Pine	69	156.0	71.0	0.218	0.299
	33	White Pine	70	56.3	--	0.104	--
		White Pine	69	180	135	0.177	0.196

APPENDIX IV, Con't.

Area	Sample Number	Species	Year of Foliage	Fluoride, PPM First Sampling	Fluoride, PPM Second Sampling	I.I. First Sampling	I.I. Second Sampling
	37-A	Mt. Maple	70	--	425	--	--
	38-A	Lodgepole Pine	70	--	57.5	--	0.080
		Lodgepole Pine	69	--	363	--	0.414
	40-A	White Pine	70	--	43.0	--	0.006
		White Pine	69	--	41.5	--	0.003
	41	Ponderosa Pine	70	--	16.5	--	0.000
		Ponderosa Pine	69	--	63.0	--	0.000
	42	White Pine	70	--	18.0	--	0.000
		White Pine	69	--	45.0	--	0.166
	43	Ponderosa Pine	70	--	7.5	--	0.001
		Ponderosa Pine	69	--	25.5	--	0.000
	44	White Pine	70	--	9.0	--	0.000
		White Pine	69	--	27.0	--	0.000
Glacier Park	11a*	Lodgepole Pine	70	10.0	--	--	--
	11b*	Lodgepole Pine	69	65.0	--	--	--
	8a*	Lodgepole Pine	70	1.0	--	--	--
	8b*	Lodgepole Pine	69	29.0	--	--	--
	9a*	Lodgepole Pine	70	11.0	--	--	--
	9b*	Lodgepole Pine	69	21.0	--	--	--
	9	Oregon Grape	70	9.0	--	0.102	--
	11	Lodgepole Pine	70	3.3	11.5	0.005	0.000
		Lodgepole Pine	69	15.0	31.0	0.175	0.000
	12a	Ceanothus	70	11.0	11.5	0.013	--
	15	Douglas-fir	70	7.3	15.0	0.000	0.000
		Douglas-fir	69	28.0	36.0	0.122	0.051
	16	Douglas-fir	70	13.0	--	0.000	--
		Douglas-fir	69	66.3	--	0.330	--
	33.5	Lodgepole Pine	70	5.3	12.0	0.000	0.000
		Lodgepole Pine	69	21.3	23.5	0.010	0.004

APPENDIX IV, Con't

Area	Sample Number	Species	Year of Foliage	Fluoride, PPM First Sampling	Fluoride, PPM Second Sampling	I.I. First Sampling	I.I. Second Sampling
	34	Ponderosa Pine	70	6.3	5.0	0.000	0.000
		Ponderosa Pine	69	--	17.0	.029	0.000
	35	Ponderosa Pine	70	5.5	6.5	0.000	0.000
		Ponderosa Pine	69	10.0	18.0	0.000	0.002
	48	Lodgepole Pine	70	--	10.5	--	0.000
		Lodgepole Pine	69	--	27.5	--	0.002
Coram Experimental Forest	1	Pine Grass	70	15.0	12.0	--	--
	2	Serviceberry	70	14.3	26.3	0.001	--
	3	White Pine	70	6.0	8.0	0.000	0.000
		White Pine	69	27.5	18.5	0.023	0.000
	4	Larch	70	10.5	10.0	0.006	0.000
	5	Pine Grass	70	11.0	15.5	0.000	--
	6	Serviceberry	70	20.0	21.3	0.004	--
	7	White Pine	70	6.0	11.5	0.000	0.000
		White Pine	69	24.0	7.0	0.055	0.000
	8	Larch	70	8.0	8.5	0.000	0.000
	9	Pine Grass	70	5.0	7.5	--	--
	10	Serviceberry	70	10.5	12.0	0.005	--
	11	White Pine	70	8.0	7.5	0.000	0.000
		White Pine	69	9.5	9.5	0.000	0.000
	12	Larch	70	6.0	7.5	0.000	0.000
	13	Pine Grass	70	7.8	13.8	--	--
	14	Serviceberry	70	9.5	12:0	0.005	--
	15	White Pine	70	17.5	4.0	0.007	0.000
		White Pine	69	15.5	7.0	0.007	0.000
	16	Larch	70	16.3	10.5	0.007	0.000
Hungry Horse Reservoir	13a*	Lodgepole Pine	70	2.0	--	--	--
	13b*	Lodgepole Pine	69	12.0	--	--	--

APPENDIX IV, Con't

Area	Sample Number	Species	Year of Foliage	Fluoride, PPM		I.I.	
				First Sampling	Second Sampling	First Sampling	Second Sampling
	12b	White Pine	70	9.0	--	0.000	--
		White Pine	69	5.0	--	0.000	--
	13	White Pine	70	2.0	7.5	0.000	0.000
		White Pine	69	5.0	9.5	0.000	0.000
	14	White Pine	70	6.0	4.0	0.000	0.000
		White Pine	69	9.0	8.5	0.000	0.000
	17	White Pine	70	6.3	7.5	0.000	0.000
		White Pine	69	11.5	10.5	0.010	0.000
	18	White Pine	70	7.5	8.5	0.000	0.000
		White Pine	69	29.5	24.0	0.062	29.5

Appendix V

REGRESSION ANALYSES OF FLUORIDE
ON INJURY INDEX[1]

	Shrubs	Conifers 1969	Conifers 1970
n	60	130	67
Slope	—.002318	.0001297	.0001038
Y - Intercept	2.461	.122416	.0692
F - Ratio for Slope	.5136	10.9345	.970
Significance of F - ratio	N.S.[2]	H.S.[3]	N.S.
Correlation	—.094	.2805	.1213
Significance of Correlation	N.S.	H.S.	N.S.

[1] *Data from first sampling period only*
[2] *N.S. — Non significant, 95 percent level.*
[3] *H.S. — Highly significant, 99 percent level.*

Appendix VI

FLUORIDE ACCUMULATION LEVELS IN INSECTS

Insect	Date Collected	PPM* Fluoride
Pollinators:		
Bumblebee — *Bombus* sp.	August 12, 1970	406.0
Bumblebee — *Bombus* sp.	June 1, 1970	194.0
Sphinx moth — *Hemaris* sp.	June 1, 1970	394.0
Honey bee — *Apis mellifera*	June 1, 1970	221.0
Skipper butterfly — *Erynnis*	August 12, 1970	146.0
Wood nymph butterfly — *Cercyonis* sp.	August 12, 1970	58.0
Foliage feeders:		
Weevils — Mixed curculionids	June 1, 1970	48.6
Grasshoppers — *Melanoplus* sp.	August 12, 1970	31.0
Larch Casebearer — *Coleophora laricella*	June 1, 1970	25.5
Cicadas — Cicadidae	June 1, 1970	21.3
Cambium Feeders:		
Engraver beetles — *Ips* sp.	October 9, 1970	52.5
Flathead beetle Mixed buprestids	June 1, 1970	20.0
Red turpentine beetle — *Dendroctonus valens* LeConte	June 1, 1970	11.5
Douglas-fir beetle — *Dendroctonus pseudotsugae* Hopk.	October 9, 1970	9.4
Flatheaded beetle larvae — Mixed buprestids	October 9, 1970	8.5
Predators:		
Ants	June 1, 1970	170.0
Ostomids — *Temnochila* sp.	June 1, 1970	53.4
Damsel flies — *Argia* sp.	June 1, 1970	21.7
Longlegged fly — *Medeterus* sp.	October 9, 1970	10.2
Ostomid larvae	October 9, 1970	6.1
Miscellaneous Insects:		
Long horned beetles Mixed Cerambycids	August 12, 1970	47.5
Click beetles Mixedelaterids	June 1, 1970	36.0
Black Scavanger Cerambycid	June 1, 1970	18.8

**PPM = parts per million by dry weight*

APPENDIX VI, Con't

CONTROL INSECT SAMPLES

Insect	Date Collected	PPM* Fluoride
Larch casebearer	June 1, 1970	16.5
Bark beetle — *Ips* sp.	October 9, 1970	11.5
Honey bees	June 1, 1970	10.5
Damselflies	June 1, 1970	9.2
Grasshoppers	August 12, 1970	7.5
Bumblebees	June 1, 1970	7.5
Barkbeetles — *Dendroctonus valens*	June 1, 1970	4.8
Flathead beetles	June 1, 1970	3.5

Appendix VII

LARCH CASEBEARER PER 100 SPURS SAMPLED

Miles from plant	Radii 1	2	3	4	5	6	7	8	9	10	Ave.
1/4	--	--	--	--	--	--	--	0	--	--	0
1/2	--	0	0	--	--	--	--	0	14.4	17.4	6.4
1	33.4	13.0	0	--	--	--	--	--	.2	16.4	12.6
2	15.8	8.6	--	0	--	--	--	.2	0	8.0	4.9
4	27.6	1.4	.75	0	--	0	.4	17.4	--	1.2	6.3
8	--	--	--	--	--	--	--	5.0	--	12.8	8.9
Ave.	25.6	5.6	.25	0	--	0	.4	4.5	4.9	11.2	

Checks: No. 1 = 8.6; No. 2 = 0; No. 3 = 0; No. 4 = 27.6

Appendix VIII

PINE NEEDLE SCALES PER 600 LODGEPOLE NEEDLES

RADII

Miles from plant	1		2		3		4		5		6		7		8		9		10		Ave.	
	69*	70*	69	70	69	70	69	70	69	70	69	70	69	70	69	70	69	70	69	70	69	70
1/4	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
1/2	--	--	1085	229	140	40	--	--	--	--	--	--	--	--	--	--	--	--	--	--	612	134
1	1	0	4	1	220	140	--	--	--	--	--	--	--	--	--	--	--	--	--	--	75	47
2	55	38	10	0	28	2	99	11	0	3	10	1	--	--	0	0	0	0	--	--	25	7
4	0	0	0	0	0	0	0	0	138	2	0	0	57	3	2	1	--	--	1	0	21	1
8	26	11	2	0	--	--	0	0	272	149	9	0	0	0	0	0	0	0	0	2	34	18
Ave.	20	12	220	46	97	45	33	4	137	51	6	.3	28	1	1	.3	0	0	.5	1		

Checks: #1 = (0—0_); #2 = (0—0); #3 = (1—0); #4 = — Ave. = .3

**69 = 1969 Foliage*
**70 = 1970 Foliage*

Appendix IX

PINE NEEDLE SCALES PER 600 PONDEROSA NEEDLES

Miles from plant	RADII 1		2		3		4		5		6		7		8		9		10		Ave.	
plant	69*	70*	69	70	69	70	69	70	69	70	69	70	69	70	69	70	69	70	69	70	69	70
1/4	365	71	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	365	71
1/2	--	--	--	--	29	1	--	--	--	--	--	--	--	--	--	--	--	--	12	0	20	.5
1	1	0	2	1	--	--	--	--	--	--	--	--	--	--	6	0	0	0	147	35	37	7
2	--	--	0	0	43	0	0	0	--	--	--	--	--	--	--	--	--	--	--	--	14	0
4	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0	0	--	--	0	0	0	0
8	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0	0	0	0
Ave.	183	35	1	.5	36	.5	0	0	--	--	--	--	--	--	3	0	0	0	79	17		

Checks #1 (6—0_); Check #2 (—); Check #3 (—); Check #4 (4—0_) Ave (5—0)

**69 = 1969 Foliage*
**70 = 1970 Foliage*

Appendix X

"REGRESSION ANALYSIS OF PINE NEEDLE SCALES ON FLUORIDE CONTENT"

Radius	Plot Number	Y Number of Scales	X Fluoride Content
1	3	1	40.7
	4	55	18.5
	5	0	9.0
	7	26	4.5
2	2	1085	100.8
	3	4	124.7
	4	10	17.3
	5	0	16.0
	7	2	8.5
3	2	140	496.5
	3	220	294.5
	4	28	85.5
	5	0	42.8
4	4	99	286.3
	5	0	53.3
	7	0	11.0
5	4	0	228.7
	5	138	56.5
	7	272	28.5
6	4	10	140
	5	0	27.0
	7	9	18.8
7	5	57	51.5
	7	0	14.0

APPENDIX X, Con't

Radius	Plot Number	Y Number of Scales	X Fluoride Content
8	4	0	56.0
	5	2	28.1
	7	0	14.0
9	4	0	41.5
	7	0	4.0
10	5	1	20.8
	7	0	4.7

Linear Regression Analysis

$Y = A+BX$
$A = 42.036$
$B = 0.365$
Correlation Coefficient = .201 N.S.[1]

[1] *Non-significant*

The Forest Service of the U.S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.